ARCTIC

Journal of the Arctic Institute of North America

Vol. 10, No. 3 Published in Montreal, Quebec 1957

CONTENTS

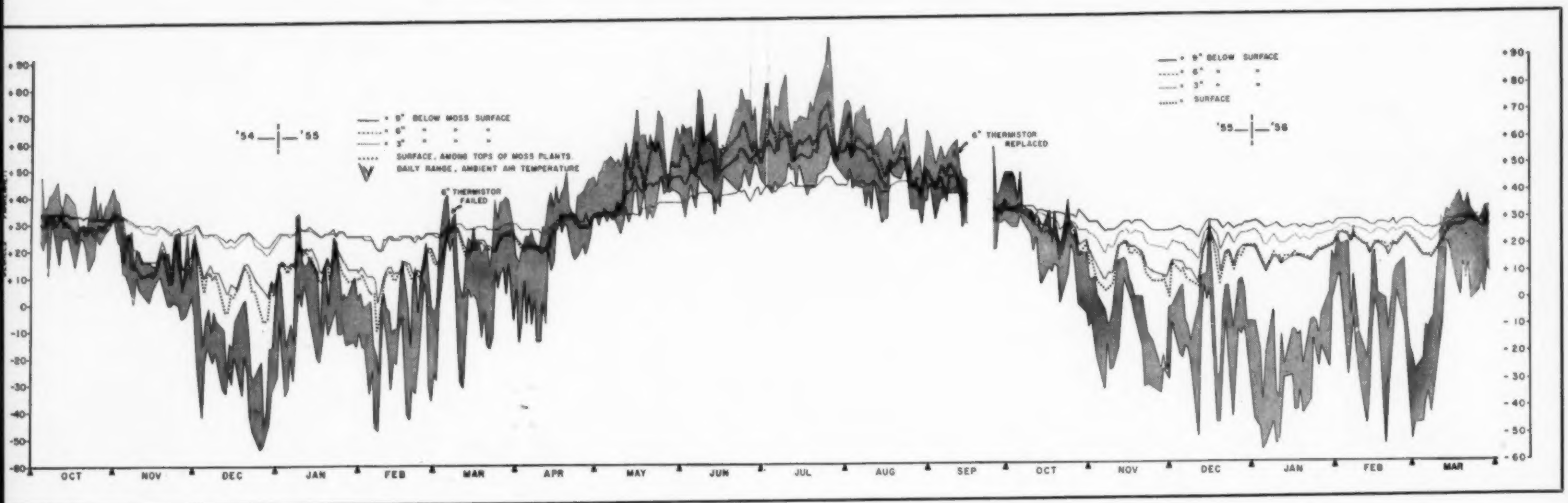

Fig. 1. Subarctic-spruce, air and soil temperatures, 1954-56.

OBSERVATIONS ON THE BIOCLIMATE OF SOME TAIGA MAMMALS

William O. Pruitt, Jr.†

WHILE the study the ecology of small mammals of the tundra regions of North America appears to be progressing rapidly, the ecology of small mammals of the transcontinental subarctic forest or taiga seems by comparison woefully neglected. Indeed, there are a number of common misconceptions about the taiga environment in general. This state of affairs undoubtedly has been brought about by three factors: (1) the lack of biological stations with year-round research programs in the taiga; (2) the natural curiosity of temperate zone biologists regarding the completely foreign tundra environment; and (3) the acknowledged difficulty of winter field work in the taiga, particularly when one depends on mechanical or electrical devices. This paper will attempt to correct some of the common misconceptions about the bioclimate of some of the small mammals inhabiting the taiga and also to suggest avenues of needed research.

This study was initiated while I was employed as Biologist at the Arctic Aeromedical Laboratory, Fairbanks, Alaska. I am grateful to the Laboratory for supplies, equipment and support and to the University of Pennsylvania, School of Medicine for continuing support through contract with the United States Air Force, Office of Scientific Research of the Air Research and Development Command. I am grateful to Mrs. William D. Berry and Mr. Charles V. Lucier for their great assistance during 1954-5 and 1955-6, respectively. Without their constant devotion to accuracy and observation this study could not have been made. Especial thanks should go to Mrs. Ladessa Nordale of Fairbanks, Alaska for permission to use the land upon which the principal bioclimate study area was established.

In 1954 several one-acre quadrats for the study of population fluctuations of small mammals were established at widely scattered points in Alaska. Three of these quadrats, because of their relative accessibility, were selected for more detailed microclimatic study. Two of these, an area of subalpine spruce and an area of Arctic-Alpine tundra, are situated in the upper Gulkana River drainage and are being investigated by Dr. L. L. Hufman of Paxson Lake, Alaska. The analysis and discussion of the data from them will comprise separate reports by us. The third area, identified on charts and specimen labels as "SPR," forms the basis of the present report.

---

† Research Associate, University of Pennsylvania, School of Medicine, Department of Physiology. (Author's address: Box 282, College, Alaska)

This quadrat is situated in NE ¼ Sec. 19, T 1 S, R 1 E of the Fairbanks Meridian, Alaska. It consists of a generally level moss-covered substrate with a mature forest of white spruce *(Picea glauca)*, balsam poplar *(Populus balsamifera)* and white birch *(Betula papyrifera)*. Also present are alders (*Alnus* spp.), a few willows (*Salix* spp.) and scattered tamaracks *(Larix laricina)*. The entire stand comprises only some 80 acres of mature forest and is fast disappearing due to cutting for firewood. This stand was selected for study since it appears to be the only sizable remnant of virgin spruce forest within many miles of Fairbanks that is accessible by road all year. The acre under study lies in a stand of some 20 acres which is bounded on the north by Peede Road and on the south by Chena Slough, one of the distributaries of the Chena River (U. S. G. S. Fairbanks D-1 Quadrangle). From the air one can see that the entire region has been worked and reworked by the river, the present-day vegetation being a mosaic of mature forest, burned and cut-over brush land and interlacing sloughs, active, stagnant and filled-in. The study area resembles to a remarkable degree the taiga described by Keller (1927). A test hole sunk to a depth of 3 feet in summer showed no frozen ground.

This plot is equipped with 100 wire markers equally spaced over it so that traps may be placed every year in the same spot. On October 4, 1954, a series of 18 thermistor assemblies was installed on the plot. The sensitive elements of these assemblies were Negative Temperature Coefficient Resistance units, Type L2005-200-89, manufactured by Keystone Carbon Company, St. Marys, Pennsylvania. The units were connected to 24 ga. two-conductor 18-#36 copper strand wire with double-weight thermoplastic insulation and were protected by black "Microsol" plastic coatings. The assemblies were prepared by Mr. Kent Culver of Wood and Metal Products Company, Bloomfield Hills, Michigan. Thermistor resistances were read on a Simpson Model 260 volt-ohm-milliammeter. Air temperatures at 6 feet above the ground were taken with Arctic Maximum and Arctic Minimum thermometers, U. S. Army Signal Corps type. All temperatures are given in degrees Fahrenheit. The area has been visited almost daily since October 4, 1954, with the exception of Saturdays and Sundays. If especially interesting weather conditions developed visits were made on these days also.

The thermistors whose records are of greatest interest are installed near the center of the plot under a cover of spruce varying from 3 to 9 inches DBH and are inserted into the mossy forest floor at 9, 6 and 3 inches below the surface and at 0 inches among the tops of the moss plants. The 9-inch thermistor rests at the bottom of the moss just above the mineral soil. Thus we have an essentially continuous record of the thermal environment of the habitat of the small mammals which use the forest floor (Fig. 1).

The dominant small mammal on this plot is *Clethrionomys rutilus*, the boreal red-backed vole. Other mammals taken, observed or sign noted on the plot are shrews (*Sorex* spp.), red fox *(Vulpes fulva)*, marten *(Martes americana)*, weasels *(Mustela erminea* and *M. rixosa)*, red squirrel *(Tamiasciurus hudsonicus)*, flying squirrel *(Glaucomys sabrinus)*, snowshoe hare *(Lepus americanus)* and moose *(Alces americana)*. Marten tracks have

been seen only once, the other mammals have been noted many times. Observations on the behaviour and population fluctuations of some of these mammals will be covered in separate reports.

Let us now examine the environment of the forest floor. This becomes the year-round bioclimate of the red-backed vole and the shrews and during the period of snow cover that of the weasels, and for long periods, also that of the red squirrel (Pruitt and Lucier, in press).

Snow-free period

In the spring of 1955 the snow cover had completed its disappearance by May 14 (Fig. 2). At this time the upper layers of moss warmed up rather suddenly and their daily temperature fluctuations began to agree with those of the ambient air. The 9-inch level continued its slow rise, however, and many times acted independently of the ambient air. The absolute maximum of the air temperature occurred on July 26 when this reached +97.5°. On this day also occurred the absolute maxima at 3-inch and surface levels. The absolute maximum of +47° at 9 inches did not occur until August 3. From these peaks the temperatures at all levels began an irregular descent until the time of the fall overturn. At this date, about October 1, the temperature of the air fell below that of the substrate and the moss surface temperatures started to fall below those of the deeper layers. This event may be called the *thermal overturn.*

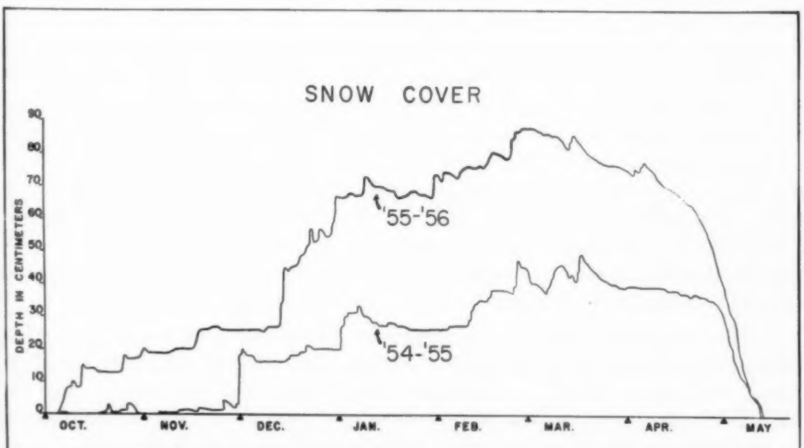

Fig. 2. Snow cover, subarctic-spruce area, winter 1954-5 and winter 1955-6.

It should be noted how the fluctuations at the 9-inch level follow those of the ambient air more closely during the snow-free period than during the periods of snow cover.

Snow period

After the fall thermal overturn the temperatures of the upper moss layers fall more rapidly than do the deeper ones. From the time of the overturn until the snow cover reaches a depth of 15-20 centimetres the fluctuations in temperature are quite marked and agree well with the fluctuations in ambient air temperature. After the snow cover reaches this critical depth (Fig. 2) the fluctuations at the upper moss layers smooth out remarkably and the rate of fall at the lower moss layers lessens. It is noteworthy that the arrival of this critical snow thickness is usually accompanied by a change in behaviour of the forest floor mammals. Before this thickness is reached activity of shrews and red-backed voles is common on the snow surface; after this thickness is reached surface activity is markedly reduced. This phenomenon has also been noted in the Eurasian taiga by Formosov (1946). This critical snow thickness may well be called the *hiemal threshold.* In 1954 the hiemal threshold was not reached until December, while in 1955 it was reached in late October. The period between the thermal overturn and the hiemal threshold is undoubtedly the most critical interval in the annual cycle of the bioclimate of the forest floor mammals, because during this period occur the greatest fluctuations in bioclimate temperatures. The onset of the thermal overturn appears to be governed by the regular decrease in solar radiation, whereas the appearance of the hiemal threshold is governed by the more or less fortuitous date of arrival of the snow cover which varies greatly from year to year.

The absolute minimum at 6 inches occurred on December 25-26, 1954, when a temperature of $+18.5^\circ$ was recorded. The absolute minima at moss surface, 3 inches and 9 inches did not occur until February 8, 9 and 10, 1955, when the temperatures there reached -9.5°, $+0.5^\circ$, and $+20^\circ$, respectively. This sequence nicely illustrates the insulating properties of taiga snow. The "cold snap" in late December, 1955, occurred with a cover of 19 centimetres of loose, uncompacted snow and the 9-inch level reached $+21^\circ$. During January a thaw occurred with several falls of wet, heavy snow and accompanying compaction of the cover. During the "cold snap" of early February, 1955, the 9-inch temperature reached its minimum for the winter, even though the snow cover was now 22 centimetres in thickness and the ambient air fell to only -47°, a point 7 degrees above the absolute minimum.

The subnivean temperature regime of the winter 1955-6 was somewhat different from that of the preceding winter. The thermal overturn occurred about October 4, the first measurable snow cover on October 10, and the hiemal threshold during the last 10 days of October. The absolute minima at all depths occurred on December 12 when the moss surface reached $+5^\circ$, the 3-inch layer $+6^\circ$, the 6-inch layer $+15^\circ$ and the 9-inch layer $+23^\circ$. For the rest of the snow period the moss surface, with the exception of one $+6^\circ$ reading, did not drop below $+11^\circ$; the 3-inch layer, not below $+11^\circ$; the 6-inch layer, not below $+19^\circ$; and the 9-inch layer, not below $+26^\circ$. The fluctuations were not so marked as those of the previous winter. For nine consecutive visits in early February, 1956, the 9-inch layer remained

constant at +29.5°, even though the ambient air fluctuated between +24° and −28°.

The thermal regime of the 6-inch layer appears to have been different in the two winters, but because the thermistor was replaced during the intervening summer this difference may be an artifact due to slightly different positions. I have noted, however, in the thermal gradient of peat and coniferous needle litter in a bog in Cheboygan County, Michigan, a "thermocline" similar to that which occurred in the SPR area during the winter 1954-5. In the peat of the temperate zone the irregularity occurred between 1 and 3 inches below the surface.

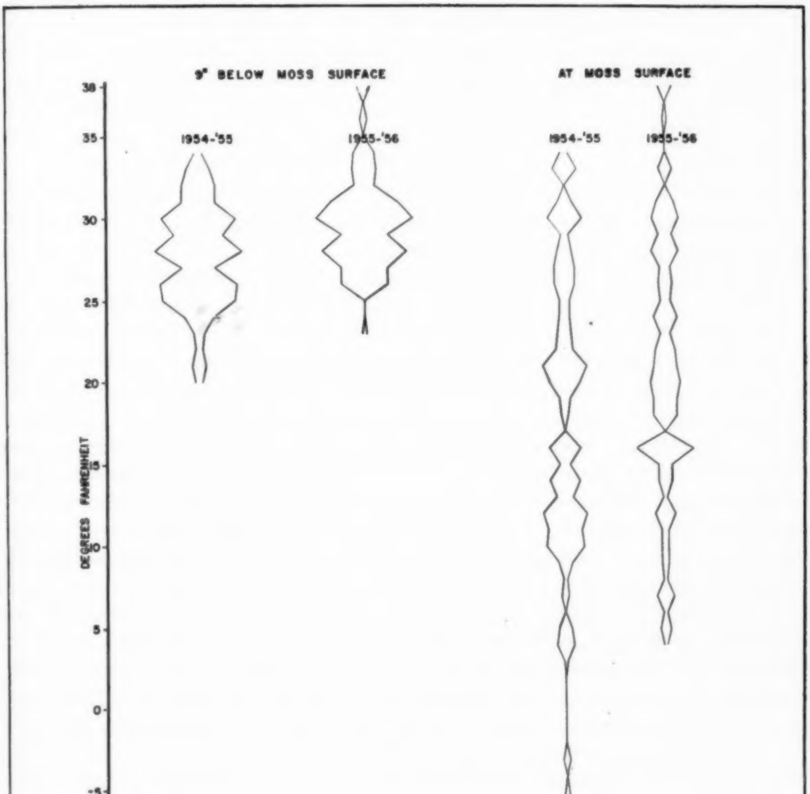

Fig. 3. Climograph of subnivean environment, winter 1954-5 and winter 1955-6.

One should note also the lag in temperature drop at the 9- and 6-inch layers when there is a marked drop in ambient air temperature during periods of snow cover, and how quickly these temperatures recover; and conversely how slowly they rise when the ambient air temperature rises during the summer and how quickly they recover. There is an apparent tendency to return toward +32°.

Discussion

From the foregoing resumé of the thermal environment of this sample of taiga one may make several generalizations. One feature of the forest floor environment is its stable temperature; comparatively warm in winter and cool in summer. During the two winters and one summer considered here the 9-inch temperature varied only 27 degrees while that of the air ranged through 152 degrees. Figure 3 graphically illustrates the stability of this environment during the periods of snow cover. It also illustrates the effectiveness of the moss cover itself as an insulator and, together with Figure 2, the effect of different thicknesses of snow cover on range and fluctuations of subnivean temperatures. A climograph such as this is constructed by plotting the frequency of observations of a given temperature on the abscissa and the temperatures on the ordinate. A line joining these points gives the resulting climograph figure. A completely stable environment would result in a horizontal line figure while an infinitely variable one would result in a vertical line figure. Scholander *et al.* (1950a, 1950b, 1950c) have shown that the physiological critical temperature of small mammals of taiga and tundra generally prevents them from using the supranivean environment for more than a few moments. Thus, the major adaptation to the taiga which these mammals exhibit is behaviour patterns that cause them to abandon surface activity almost entirely at the time of the hiemal threshold. A complete description of these behaviour patterns, the environmental stimuli and the releasing mechanisms, if any, would be a fruitful and revealing investigation. Those kinds of small mammals which are morphologically unable to take advantage of the subnivean environment or whose behaviour patterns are such that they cannot become subnivean are generally unable to ecise the taiga. Johnson (1951, 1954) has confirmed the suitability of this subnivean environment for small mammals. He puts great emphasis on the "meteorological event" or "cold snap." This is undoubtedly important in the lives of the animals living above the snow, but the "cold snap" is a distant and foreign event in the lives of the subnivean animals.

The temperature regime of the forest floor under the snow is very stable in time but not in space. Because of the protection afforded by the trees, the snow cover is not uniform in depth but is interrupted by bowl-shaped depressions about the base of each tree. In the language of the Kobuk Valley Eskimo these depressions are known as *"qámaniq."* Here the snow depth varies from scant at the tree base, slowly increasing towards the branch tips and suddenly increasing at the edge of the "snow shadow." The temperature regime varies from cold and fluctuating at the tree base to warm and stable beyond the edge of the qámaniq.

In the fall of 1954 a series of nine thermistors was buried 1 inch deep and at 6-inch horizontal intervals from the base of the south side of the trunk of a 12-inch DBH spruce out to 54 inches from the trunk. The last three thermistors were beyond the edge of the qámaniq. Sample readings are given in Table 1. Preliminary results from a study using subnivean live traps indicate that *Clethrionomys* tend to avoid the qámaniq in favour of those parts of their home range with a full snow cover.

Bader *et al.* (1954) observed that the air within a snow mass is practically always saturated with water vapour. This situation undoubtedly obtains in the atmosphere of a burrow or tunnel system through the moss under the snow. This saturated atmosphere offers ideal conditions for intraspecific communication by scent. As I have shown elsewhere (in press) for *Blarina*, a genus of temperate zone shrews, a saturated atmosphere in their tunnels is an essential feature of the habitats in which they occur. The genera of taiga shrews, *Sorex* and *Microsorex*, being smaller than *Blarina*, are probably even more susceptible to changes in atmospheric moisture.

Table I

Date	Air temperature	Base of trunk		Beyond qámaniq	
		Temperature	Snow depth	Temperature	Snow depth
Nov. 22, 1954	+ 2° F.	+9.5° F.	trace	+14° F.	1 cm.
Dec. 22, 1954	—25° F.	—2.5° F.	8 cm.	+9.5° F.	17 cm.
Jan. 28, 1955	—11° F.	+2.5° F.	8 cm.	+13° F.	20 cm.
Feb. 21, 1955	—33° F.	—6.5° F.	13 cm.	+10.5° F.	35 cm.

The silence of the subnivean environment must be a potent factor in the evolution of the sensory systems of the mammals inhabiting it. This silence can be experienced by a human during a stay in a snowhouse. Disturbance of the snow cover by footsteps close by fairly explodes upon the ears against a background of silence. When the uncommon winds occur the roots and bases of trees creak and crackle.

Thus the subnivean environment of the taiga is characterized by temperatures with a narrow range of variation and rather gentle fluctuations, silence, darkness and a saturated atmosphere. The supranivean environment, in contrast, is characterized by air that varies from saturated to very dry and by air that can be still or in motion, by cyclic light and darkness, and by temperatures with a wide range of variation and markedly violent fluctuations. In addition the snow cover acts not as an insulating blanket above the animal but as a hindering mass through which the animal must wade. These factors and the morphological and behavioural adaptations to them have been considered in the classic work by Formosov (1946). Not only does the supranivean animal have to contend with the snow underfoot, but the snow which collects on the trees also exerts a powerful effect on arboreal activity. Formosov noted that this snow which collects on trees is known to the people of the Siberian taiga as *"kukhta"* or *"navis."* The Kobuk Valley Eskimo use the term *"qalí"* to refer to the snow which collects

on trees, as distinct from *"apí,"* the snow which collects on the ground. The Athabaskans of the Fort Yukon region, Alaska, use the term *"zá"* for snow in a general sense and *"dé-za"* for snow that collects on trees. Biologists studying the taiga would do well to use these and other snow terms of northern peoples since English is notably deficient in them.

In summary, we see that those small mammals which have become adapted to utilize the subnivean portion of the subarctic taiga have available an environment that is climatically quite distinct from that which is 1 to 3 feet above them. No other ecotone, except the hydrosphere-atmosphere interface, affords such a sharp environmental gradient as does the snow cover in the subarctic taiga. Knowledge of the presence of this sharp ecotone between what are actually two quite distinct environments results in obvious implications for our understanding of such biological phenomena as geographic distribution patterns, ecological segregation, "Bergmann's Rule," "Allen's Rule," "Merriam's Life Zones," and seasonal changes in behaviour patterns.

References

Bader, H. *et al.* 1954. Snow and its metamorphosis. SIPRE Translation No. 14 of Bader, H., R. Haefli, E. Bucher, J. Neher, O. Eckel and Chr. Thams-1939-Der Schnee und seine Metamorphose. Beiträge zur Geologie der Schweiz. Geotechnische Serie, Hydrologie, Lieferung 3, Bern.

Formosov, A. N. 1946. The covering of snow as an integral factor of the environment and its importance in the ecology of mammals and birds. Material for Fauna and Flora of USSR, New Series, Zoology 5: 1-152 (Russian with French summary).

Johnson, H. M. 1951. Preliminary ecological studies of microclimates inhabited by the smaller arctic and subarctic mammals. Proc. Alaska Sci. Conf. 1951 (published 1953): 125-131.

————— 1954. Winter microclimates of importance to Alaskan small mammals and birds. Unpubl. Ph.D thesis, Cornell University

Keller, B. A. 1927. Distribution of vegetation on the plains of Euroepan Russia. J. Ecol. 15: 189-223.

Pruitt, W. O., Jr. and C. V. Lucier. Observations of winter activity of red squirrels *(Tamiasciurus hudsonicus)* in interior Alaska. J. Mamm. in press.

Scholander, P. F., V. Walters, R. Hock and L. Irving. 1950a. Body insulation of some arctic and tropical mammals and birds. Biol. Bull. 99: 225-236.

Scholander, P. F., R. Hock, V. Walters, F. Johnson and L. Irving. 1950b. Heat regulation in some arctic and tropical mammals and birds. *Ibid.*, 237-258.

Scholander, P. F., R. Hock, V. Walters, and L. Irving. 1950c. Adaptation to cold in arctic and tropical mammals and birds, in reference to body temperature, insulation and basal metabolic rate. *Ibid.*, 259-271.

VARIATIONS OF BLUE, HOH, AND WHITE GLACIERS DURING RECENT CENTURIES*

Calvin J. Heusser†

GLACIERS in the Olympic Mountains of western Washington, as elsewhere in North America, enlarged in late-postglacial time and attained positions from which they have receded conspicuously. Former locations of the ice are marked by moraines and overridden surfaces which the regional vegetation is slowly invading. An examination of aerial photographs[1] of glaciers on Mt. Olympus taken in 1939 and 1952 clearly reveals the progress of recession. In 1952 Blue and Hoh glaciers (Fig. 1) appear rather inactive whereas a photograph of Blue Glacier taken about the turn of the century (Fig. 2) shows an actively discharging tongue, well in advance of its position in the early 1950's.

About 1900 glacier termini were nevertheless well behind positions reached when the ice stood farther down the valleys in past centuries. No written accounts or measurements are available from this pre-1900 period, although the ages of trees growing on moraines and outwash offer the means for fixing positions of the glaciers during the time before the earliest observations. The minimum periods elapsed since glaciers may have been even farther advanced are established by the ages of the oldest trees in the forests beyond the recent outermost limits of the ice.

A reconnaissance of Blue and Hoh glaciers and the vicinity of White Glacier was made during the 1955 summer, and the former limits of the ice were determined and dated. The purpose was to record the variations of Mt. Olympus glaciers so that the climate of this region during the last several centuries might be interpreted from these changes and compared with other localities where similar studies have been made. The relationship between glacier and climate changes has been demonstrated in such areas as the North Atlantic (Ahlmann, 1953) and an attempt has been made to relate glacier variations and sun spots in southeastern Alaska (Lawrence, 1950a).

This work was made possible through contract with the Office of Naval Research, Department of the Navy, and a grant by the Arctic Institute of North America and carried out in co-operation with the Olympic National Park Service. This assistance is gratefully acknowledged and also that

---

† Research Associate, American Geographical Society of New York.

[1] U. S. Geological Survey photographs for 1939 are GS-J8-75 and 76 and GS-J9-29; those for 1952 are GS-WR4-112 and 113.

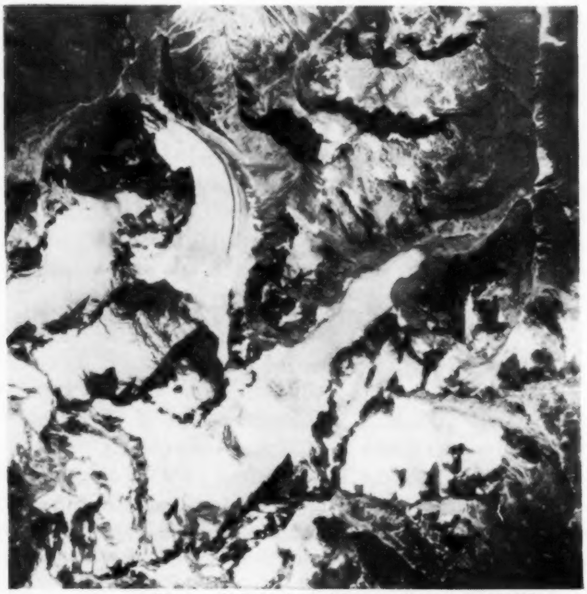

Photo: U.S. Geological Survey photograph GS-WR4-112.

Fig. 1. Aerial view of the Mt. Olympus massif showing Blue Glacier (upper left) and Hoh Glacier (middle right); White Glacier is to the left of the Blue but is not included in the photograph. October 3, 1952.

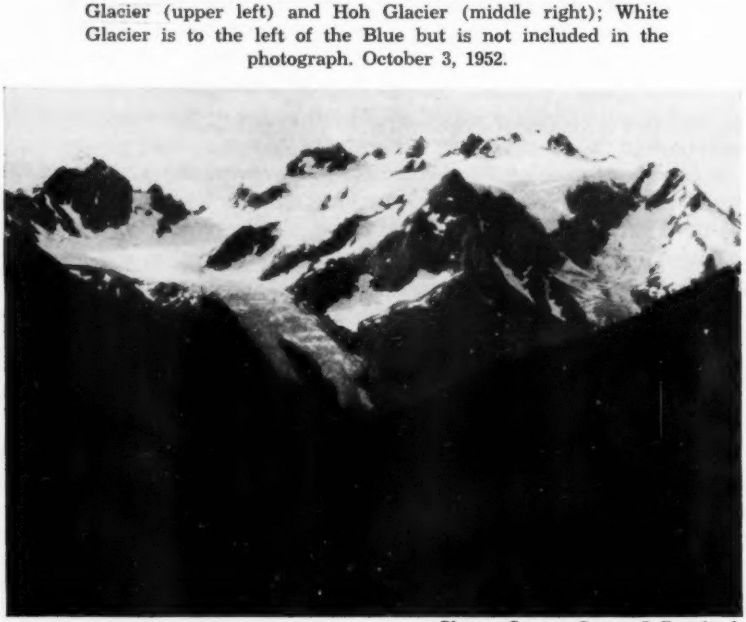

Photo: Courtesy Gunnar O. Fagerlund.

Fig. 2. Historic photograph of Blue Glacier taken about 1900 from the northwest. Mt. Olympus (7,954 feet elevation) is the highest point seen on the skyline.

given by Michael W. Hane, Richard C. Hubley, and Edward R. LaChapelle, field associates, and Gunnar O. Fagerlund and Hugh H. Bozarth of Olympic National Park.

The Blue, Hoh, and White glaciers

These glaciers descend the slopes of the Mt. Olympus complex, whose highest point is 7,954 feet above sea level, and their névé areas reach almost to this elevation (Fig. 3). The Blue curves northwestward to a terminus at approximately 4,000 feet while the Hoh flows northeastward to an elevation of about 3,600 feet (Fig. 4). White Glacier is north-northeast flowing and reaches to 4,000 feet. Hoh Glacier has a length of drainage of 3.3 miles, Blue Glacier of 2 miles, and White Glacier also of about 2 miles. The Hoh and the White flow down even gradients whereas the Blue is beset with a group of ice falls, several hundred feet in height, below the "Snow Dome" and the upper snow field of Mt. Olympus. Blizzard Pass at 6,100 feet connects the

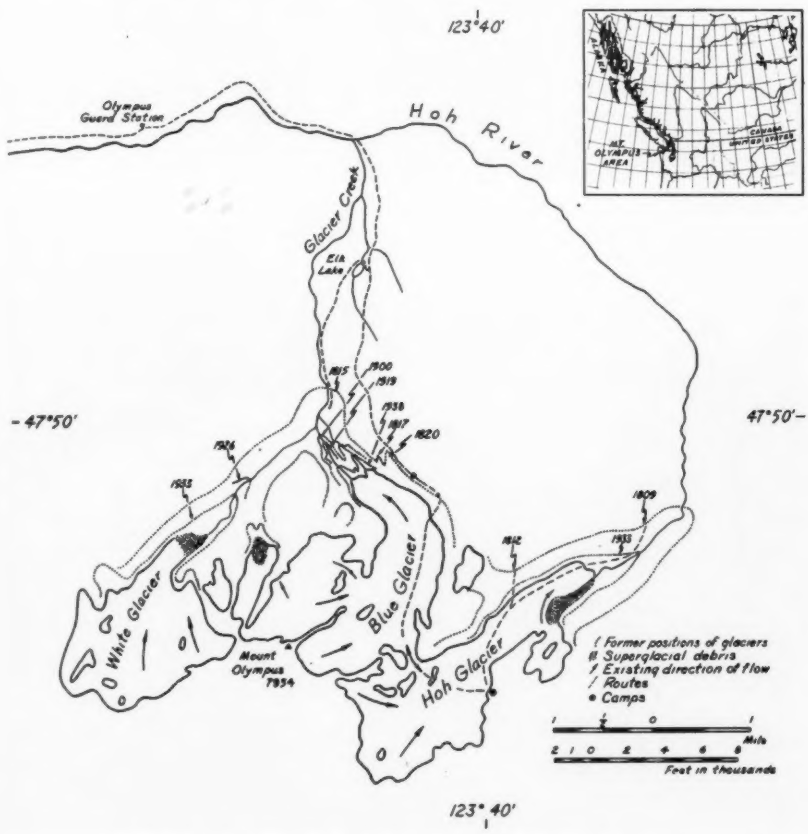

Fig. 3. Sketch map of Blue, Hoh, and White glaciers as of 1952.

Blue and the Hoh. All glaciers are geophysically temperate according to the Ahlmann (1948) classification and have firn limits at or near 5,500 feet.

Blue Glacier exhibits a diversity of features. Several medial moraines and two or three series of arch bands appear on the glacier surface. More than 100 feet above the northeast margin of the ice, at an elevation of 5,000 feet, is a sequence of lateral moraines that lower down descend into the timber. At least four of different ages occur, two of which are shown in Figure 5. Blue Glacier terminus rests above a steep slope more than a thousand feet above the valley floor. A bouldery ground moraine in the valley bottom at 2,650 feet elevation and a mile distant from the terminus marks the recent maximal extent of the glacier.

The exposed ice of Hoh Glacier is relatively clean and little broken by crevasses. A thin ablation moraine covers the tip of the snout and an inconspicuous lateral moraine blankets a small portion of the ice along the northwest edge. No distinctive recessional moraines have formed in the outwash. At the time of the last maximum, moraines were built into the forests along the valley sides and are now hundreds of feet above the glacier surface and outwash. The lowermost limit that the glacier reached at 2,900 feet elevation during the last few centuries was not visited, but it can be seen on the aerial photographs that no terminal moraine exists. It probably has been reworked by streams issuing from the terminus on account of the narrowness of the Hoh Valley.

Fig. 4. View of Hoh Glacier terminus. August 16, 1955.

Fig. 5. Moraines at 5,000 feet elevation above the northeast margin of Blue Glacier. The inner of the two weathered moraines is in the middle of the photograph and the early nineteenth century moraine, comparatively unweathered, is at the left.

The conspicuous mud flow on the southeast side of the Hoh snout (Figs. 1 and 4) is indicative of the physiographic instability of this region. The 1939 aerial photographs do not show this feature, but those from 1952 do. This suggests a disturbance that occurred some time during the 1940's or the early part of the 1950's and possibly was a result of earthquakes. White Glacier also exhibits a heavy mantle of detritus that clearly represents dynamic dumping. This earth slide has spread across the tongue above the terminal area and is shown in the 1939 aerial photographs (see GS-J8-76, also the 1944 photograph in Danner, 1955, page 39). It may be the result of an earthquake prior to the dislodgement of earth in the vicinity of the Hoh. An early photograph of White Glacier taken from across the valley in 1926 does not show this superglacial cover but what appears to be an earlier slide or morainal material (*The Mountaineer*, 1926, frontispiece). Danner (1955) states that strong earthquakes occurred in the Puget Sound area in 1939, 1946, and 1949.

Hoh Glacier is the major source of Hoh River which flows generally westward across the Olympic Peninsula and reaches the Pacific Ocean just north of Ruby Beach. Glacier Creek, a major tributary, carries the discharge of Blue and White glaciers. In the upper reaches, the Hoh River and its branches flow mainly in deep valleys, which are steep-sided, whereas

the lower course is relatively broad with gravel bars and flats. Blue Glacier can be reached by trail from the Hoh Ranger Station via Olympus Guard Station. Hoh Glacier is readily accessible by way of Blizzard Pass. Most of these places are shown in Figure 3 and on the U. S. Geological Survey map, Mount Olympus Quadrangle, 1935, Scale 1: 62,500.

Glacier variations

Botanical and geological evidence, old ground photographs, aerial photographs, and Park Service records were used to determine the positions of the ice margins during the times of maxima and up to the middle of the 1950's.

Trees growing on moraines and outwash provided most of the dates for recession. If a time interval that equals the period before trees invade the denuded terrain is added to the age of the oldest tree on a particular surface, the date of withdrawal may be fixed more accurately. Twelve years were added to the ages of trees growing on the down-valley moraines, whereas a somewhat longer interval was added in the cases of trees on moraines at higher elevations. Tree ages were obtained from cores taken with a Swedish (Djos) increment borer from the base of each trunk. Lawrence (1950b) has described the methods.

Two ancient moraines border the northeast edge of Blue Glacier at 5,000 feet elevation. Their ages are unknown although the oldest trees indicate that they are at least pre-1250 in age. The outer one of the pair, by virtue of its position, is older, but it is without trees, less extensive, and smaller in size. The younger and larger one is partly tree covered and is composed of both fine and coarse debris with angular boulders that have been subjected to prolonged weathering (Fig. 5).

The earliest datable advance of Blue Glacier took place about 1650. This date is based on the ages of an alpine fir and mountain hemlock that are growing on a morainal remnant and that were tilted by a subsequent advance in the early nineteenth century. The locality where these trees are standing is about 200 feet lower in elevation than the previously mentioned ancient moraines. Downed and rotting timber occurs on the slope and the dated trees are beside a large scarred mountain hemlock over 500 years in age. The 1650 advance extended just beyond that of the nineteenth century at this location, but elsewhere evidence of the 1650 ice thrust appears to have been buried or obliterated. Trees of the ancient forest beyond this moraine are over seven centuries old and accordingly preclude further extension of the glacier for an equivalent period.

When the Blue was at its maximum, the northeast margin of the glacier above the ice fall spilled over through two narrow defiles forming two bifurcated lateral tongues. The ice at this time curved along the ancient moraines and descended several hundred feet, dumping large quantities of boulders and glacio-fluvial material through the forests below. The ages of young trees that have invaded as these tongues receded disclose that stability of the lateral moraines was achieved in the early nineteenth

century. The western tongue withdrew about 1817 and the eastern tongue receded about 1820.

This time, as might be expected, is somewhat later than that of the recession of the lower valley snout. Recession from this recognizable outermost and lowermost position of Blue Glacier occurred about 1815, while White Glacier presumably had coalesced with the Blue and the two formed a common front. The 1952 aerial photograph GS-WR4-112 (Fig. 1) clearly shows the former boundary of the glaciers. The small tops of the young even-aged trees that became established when the glaciers receded contrast distinctly with the fuller crowns of the old trees growing beyond the former extent of the ice. Although no recessional moraines are evident in the valley below the ice fall, four are present up-glacier above the 1820 moraine near the northeast margin of the glacier; two appear to have been formed during the nineteenth century while the third was formed about 1900 and the last during the second decade of this century.

Recession of Blue Glacier between 1815 and 1900 is estimated at approximately 2,800 feet. Between 1900 and 1919 the terminus receded about 300 feet and further retreat until 1938 has amounted to about 1,500 feet. These measurements are based in part on the transfer of positions of the ice margin taken from early photographs of about 1900 (Fig. 2) and of about 1919 to the U. S. Geological Survey map entitled "Mount Olympus Quadrangle." The 1919 photograph is the property of the Committee on Glaciers of the American Geophysical Union and is on file at the American Geographical Society. As discussed by Matthes (1946, page 221) the Park Service has periodically measured the change of position of the terminus since 1938. Retreat amounted to somewhat more than 800 feet between 1938 and 1953 and an advance of 10 feet was measured in 1955. Photographs of the terminus in 1953 and 1955 (Figs. 6a and b) reveal a thickening of the snout.

Dates for the maximum of Hoh Glacier are quite similar to those for the Blue. Along the north lateral moraine, above and below the terminus, recession occurred respectively in 1812 and 1809. The lowermost point that the glacier reached in recent centuries was not visited, but it is likely that recession there was somewhat earlier than 1809. No evidence to indicate earlier advances of this glacier was located. The glacier had not exceeded its nineteenth century maximum for over 450 years. It is estimated that the terminus withdrew approximately 3,500 feet between the early 1800's and 1933; additional retreat from 1933 to 1952 has been about 3,000 feet.

Although the White Glacier was not visited except the terminal moraine, some estimates of recession are presented in so far as reliable data will allow. Retreat of the terminus between the early 1800's and 1926 has amounted to approximately 6,500 feet, between 1926 and 1933 to about 1,000 feet, and between 1933 and 1952 to 3,000 to 4,000 feet. The superglacial cover on the snout obscures the position of the ice margin so that only an approximate measurement can be given. Total recession is between 10,500 and 11,500 feet and thus is much greater than that for the Blue (4,900 feet) or the Hoh (6,500 feet). During withdrawal, the terminus advanced at least twice as indicated by certain discontinuities in the vegetation pattern on

Photo: Gunnar O. Fagerlund.

Fig. 6a. Blue Glacier terminus. September, 1953.

the outwash. The first readvance probably occurred during the 1800's and the second during the early part of the present century.

Discussion

Certain conclusions can be drawn from the foregoing data on the variations of Mt. Olympus glaciers. Since the early nineteenth century variations of the three glaciers studied appear to have been synchronous, it is likely that behaviour before and after was also synchronous. The three glaciers studied have their source areas in similar environments and all drain essentially northward. Of course, some disparity induced by local factors must be expected. Earth slides covering portions of the Hoh and White snouts exemplify an influence that may affect the rate of recession. Nevertheless, such a factor should cause only a small discrepancy in the general synchronism. Other glaciers on Mt. Olympus, notably the Hubert, the University, and the Humes, on the other hand, may have been somewhat out of phase with those studied, since their source areas are at lower elevations and their aspects are not northerly.

Hubley (1956) has analyzed the recent climate trends based on meteorological records taken on Tatoosh Island, just off the northwestern Olympic Peninsula. His graphs show relatively high precipitation and low temperatures about the turn of the century while afterward and up until the early 1940's precipitation has been low and temperatures have been rising. Since

Photo: Gunnar O. Fagerlund.

Fig. 6b. Blue Glacier terminus, from the same position at which the 1953 photograph was taken. Note the thickening of the snout as indicated by increased blocking from view of the distant summit. September, 1955.

the early 1940's this trend has reversed sharply. Variations of the glaciers studied are generally in accord with these trends, and Blue Glacier behaviour, better known than that of the Hoh or the White, agrees more closely. On the basis of the relationship shown between the glacier variations and the climatic fluctuations for this century, the important advances of about 1650 and the early 1800's would appear to be coincident with climatic conditions favouring glacier growth, that is, higher precipitation and lower temperature.

The situation in the Mt. Olympus area is not local. Longley (1954) has shown that temperatures in western Canada have been rising since the relatively cold 1880's, although since about the mid-1940's they have fallen similarly to those from Tatoosh Island. Temperate glaciers elsewhere in the Cordillera of northwestern North America have, in general, followed this trend during this period and prior to this time have behaved, with some exceptions, like those in the Olympics. In this discussion the variations of Blue Glacier will be representative of the study area for purposes of comparison with variations of other North American glaciers.

The two undated pre-1250 moraines of the Blue appear to be related to those that Harrison (1956a) has reported as corresponding to an older age than our present glaciers but younger than those dating from Wisconsin glaciation. In more recent studies in the Malaspina Glacier district, Alaska,

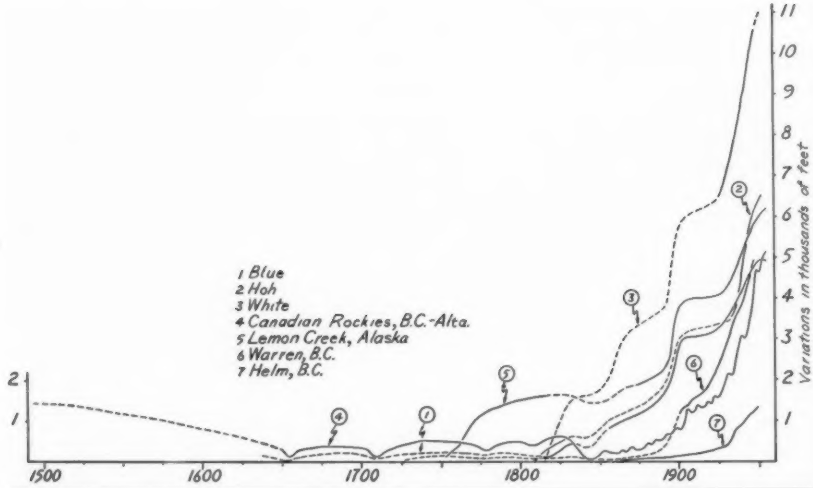

Fig. 7. Diagram representing time-distance variations for Blue, Hoh, and White glaciers and compared with those from representative glaciers elsewhere in northwestern North America. Data for the Canadian Rockies are from Heusser (1956), for Lemon Creek Glacier from Heusser (1955), and for Warren and Helm glaciers from Matthews (1951).

Plafker and Miller (1957) have been able to date an advance that seems to correlate with either or both of the ancient Blue Glacier moraines. This advance culminated between 600 and 920 A.D. in Icy Bay and between 970 and 1290 A.D. in Yakutat Bay and was followed by recession that began before 1400 and ended about 1700.

Regional glacier variations during the last few centuries are shown in Figure 7. For comparison, representative glaciers were chosen from the Canadian Rockies, Alberta-British Columbia (Heusser, 1956); the Juneau Ice Field in southeastern Alaska, Lemon Creek Glacier (Heusser, 1955); and from Garibaldi Park in southwestern British Columbia, Warren and Helm glaciers (Mathews, 1951).

The curve for the Canadian Rockies (Fig. 7) is the most detailed and extensive one, dating back to about 1500. It shows that the earliest recognizable variation in this region occurred during the mid-1600's. Blue Glacier advance during this century appears to have been contemporaneous. The second variation in the curve for the Canadian Rockies occurred during the early 1700's. Blue Glacier presumably readvanced or its rate of retreat decreased, although no evidence from which to infer its behaviour at this time is available. Warren Glacier began retreating about 1725 and Lemon Creek Glacier about 1750. It would seem that glaciers generally had been affected by the favourable conditions for glacier growth during the early 1700's. Variations are evident during the late 1700's and early 1800's and following the last, glaciers in the Olympics began to retreat with only minor halts and surges up until the 1950's.

In the Canadian Rockies and in Garibaldi Park, the second quarter of the 1800's was apparently an interval of greater glacier activity than in any comparable period in the preceding two centuries. Lemon Creek Glacier receded a relatively small amount at this time and may have readvanced slightly. In the Olympics recession was presumably slow. Since about 1850, recession for the glaciers under discussion has been generally continuous and with rates increasing in the late 1800's (Blue, Lemon Creek, and Warren) or in the early 1900's (Canadian Rockies).

The first and second decades of this century represent an interim of relatively slow retreat with some moraine formation. Evidence for this is found in all areas diagrammed in Figure 7. After 1925-30 glaciers melted back at a most rapid rate; White Glacier shows this very strikingly and more so than any of the others under consideration. The measurements by the Olympic National Park Service of Blue Glacier terminus show a particularly high retreat for the period 1939 to 1944 with subsequent smaller amounts, except for 1950-51. During the late 1940's recession was slow but between 1954 and 1955, as previously mentioned, a small advance was observed accompanied by terminal thickening (Figs. 6 a and b). Hubley (1956) has reported on this latest advance as well as others observed during 1955 in the northern Cascade Mountains of northwestern Washington and on Mt. Shasta in California. Also in this regard, Bengtson (1956) has noted the changes in the advancing front of Coleman Glacier on Mt. Baker in the Cascades, and West (1955) has written of the thickening tongue of Commander Glacier in the Purcell Mountains of British Columbia between 1947 and 1954.

The recently published curve of variations for Nisqually Glacier, Mt. Rainier (Harrison, 1956b, page 683) is in general accord with the trends represented in Figure 7. An advance of this glacier is figured during the mid-1800's, retreat is rapid in the late 1800's, readvance and moraine formation follow in the first decade of this century, and subsequent recession has been most pronounced. No advance has been registered during the 1950's, although a "wave" of ice is progressing down-glacier and has been observed since 1944. Additional data for comparison are provided by several other investigators. Cooper (1937) dated the earliest retreat of ice in Glacier Bay, Alaska as 1760. Lawrence (1950a, 1953) placed the earliest recession of the Juneau Ice Field glaciers between 1700 and 1775 and indicated a readvance during the mid-1800's. According to Lawrence (1948) in about 1740 glaciers on Mt. Hood, Oregon stood farthest advanced in recent centuries and during subsequent retreat readvanced about 1840.

As the nineteenth century advance, as well as the advances in the seventeenth and eighteenth centuries, has been greater in one area than in another, so the glacier activity in the twentieth century has varied at different places. Columbia Glacier in Prince William Sound, Alaska, for example, was at the maximum for the last 500 years between 1914 and 1922 (Field, 1937; Cooper, 1942), and Norris Glacier, flowing from the Juneau Ice Field, had not been further advanced in 1910 than for nearly 500 years (Muntz, 1955). Such noteworthy advances are known from only a few localities whereas at other places they have been found to occur as small

fluctuations. It seems evident that the conditions favouring such glacier advance can be widespread, although they may be accentuated locally.

References

Ahlmann, H. W. 1948. Glaciological research on the North Atlantic coasts. Roy. Geog. Soc. Res. Series No. 1, 83 pp.

——————1953. Glacier variations and climatic fluctuations. New York: Am. Geog. Soc., 51 pp.

Bengtson, K. E. 1956. Activity of the Coleman Glacier, Mt. Baker, Washington, U. S. A., 1949-1955. J. Glaciol. 2: 708-713.

Cooper, W. S. 1937. The problem of Glacier Bay, Alaska: a study of glacier variations. Geog. Rev. 27: 37-62.

——————1942. Vegetation of the Prince William Sound region, Alaska, with a brief excursion into past-Pleistocene climatic history. Ecol. Monogr. 12: 1-22.

Danner, W. R. 1955. Geology of Olympic National Park. Seattle, 68 pp.

Field, W. O. 1937. Observations on Alaskan coastal glaciers in 1935. Geog. Rev. 27: 63-81.

Harrison, A. E. 1956a. Multiple glaciation since the Ice Age. Science 124: 181-182.

——————1956b. Fluctuations of the Nisqually Glacier, Mount Rainier, Washington, since 1750. J. Glaciol. 2: 675-683.

Heusser, C. J. 1955. Preliminary study of the historic fluctuations of Lemon Creek Glacier terminus. *In* Prog. Rpt. Juneau Ice Field Research Proj., Alaska 1954. Am. Geog. Soc., pp. 34-41. (mimeo.).

——————1956. Postglacial environments in the Canadian Rocky Mountains. Ecol. Monogr. 26: 263-302.

Hubley, R. C. 1956. Glaciers of the Washington Cascade and Olympic Mountains; their present activity and its relation to local climatic trends. J. Glaciol. 2: 669-674.

Lawrence, D. B. 1948. Mt. Hood's latest eruption and glacier advances. Mazama 30: 22-29.

——————1950a. Glacier fluctuations for six centuries in Southeastern Alaska and its relation to solar activity. Geog. Rev. 40: 191-223.

——————1950b. Estimating dates of recent glacier advances and recession rates by studying tree growth layers. Trans. Am. Geophys. Un. 31: 243-248.

——————1953. Recession of the past two centuries. *In* Periodicity of deglaciation in North America since the late-Wisconsin maximum. Geog. Ann. 35: 83-94.

Longley, R. W. 1954. Temperature trends in Canada. Proc. Toronto Meteor. Conf. 1953: 207-211.

Mathews, W. H. 1951. Historic and prehistoric fluctuations of alpine glaciers in the Mount Garibaldi map-area. J. Geol. 59: 357-380.

Matthes, F. E. 1946. Report of the committee on glaciers, 1945. Trans. Am. Geophys. Un. 27: 219-233.

The Mountaineer. 1926. Olympic Peninsula. The Mountaineer 19.

Muntz, A. P. 1955. Recent glacier activity in the Taku Inlet area, Southeastern Alaska. Arctic 8: 83-95.

Plafker, G. and D. J. Miller. 1957. Glacial features and surficial deposits of the Malaspina district, Alaska. U.S. Geological Survey open file rpt., 13 pp.

West, R. 1955. The recent history of the Commander Glacier. Can. Alp. J. 38: 99-101.

STUDIES ON SEASONAL CHANGES IN THE TEMPERATURE GRADIENT OF THE ACTIVE LAYER OF SOIL AT FORT CHURCHILL, MANITOBA*

D. K. Brown Beckel

Soil temperature observations were made as early as 1837 (Forbes, 1837) near Edinburgh where readings were obtained at depths of 3, 6, 12 and 24 French feet (24 French feet = 25.6 English feet) using specially constructed mercury thermometers. Since then, numerous papers have been published on soil temperatures, with stress for the most part on soils of temperate climates and the economic aspects of the problem. As a result of the research, a number of factors, intrinsic and extrinsic, have been found to affect the change in soil temperature gradient throughout the year. Bouyoucos (1913, 1916) thoroughly and systematically reviewed the literature available at that time.

Since then, Crawford (1952) has published a comprehensive review of the wealth of pertinent soil temperature research. In this review, he discusses the roles played by the effect of rainfall and melting snow, snow cover, surface cover, soil-moisture content, moisture migration, thermal conductivity and diffusivity, freezing temperature of soils, daily temperature variation, temperature inversion with depth, and frost penetration and retreat. Generally, his review indicates that foremost among the extrinsic factors affecting soil temperature is the source and amount of heat given to the soil. The primary source of heat is the radiation of the sun; heat transferred to the soil by conduction is comparatively less. Latitude of the location has an important bearing on the amount of heat absorbed per unit area of surface.

Surface cover — its quantity and colour — is another important factor. It has been found that frost penetration is deeper and its disappearance slower under bare ground than under vegetal cover, since the vegetation acts as an insulatory layer to the soil. Black soil was found to thaw more rapidly and to freeze more slowly than did a light coloured soil.

The protective effect of snow cover has been known for many years. Atkinson and Bay (1940) found the depth of frost penetration changed in direct proportion to the depth of snow. They observed that in two out of

* This paper summarizes the results of D.R.B. Project D45-97-67-02 as conducted by the author while working as a member of the staff of the Defence Research Northern Laboratory at Fort Churchill, Manitoba.

three cases where there was 10 inches or more of snow, the frost depth decreased. Where there was 10 inches or less of snow, the frost depth increased correspondingly. The research of Diebold (1937) produced similar results.

The physical characteristics of the soil itself determine to a large extent its ability to conduct and absorb heat. In order of decreasing conductivity soils may be listed as sand, gravel, clay, humus and peat. Bouyoucos (1913) listed the specific heat properties of soils (Table I). Thus peat has the lowest

Table I
Specific heat properties of soils

Soil	Specific gravity	Specific Heat	
		Equal weight	Equal volume
Sand	2.664	.1929	.5093
Gravel	2.707	.2045	.5535
Clay	2.762	.2059	.5686
Peat	1.755	.2525	.4397

specific heat by volume yet the highest specific heat by weight. Moisture content alters these properties. Crawford (1952) showed that dry peat will heat or cool about twice as readily as sand or gravel, with equal application of heat. In the natural wet condition, it will heat or cool about one-third as readily, indicating the great importance of moisture content. Though sand and gravel have higher specific heats by volume than peat, and thus will heat or cool more slowly in the dry condition, Bouyoucos (1913) deduced that field moisture conditions altered the picture to the extent that the sand and gravel will cool or heat three times as rapidly as peat.

The experiments described in this paper on rates of freeze and thaw of the active layer have shown the complicated interaction of some of these factors as they occur in the Fort Churchill, Manitoba region. Since the fall of 1954 when the last of the data were collected, Cook (1955) has published his results on soil temperature measurements at Resolute Bay in the Northwest Territories. He describes and discusses the readings from two cables placed 225 feet apart in overburden of slightly different composition, but composed for the most part of frozen gravel and shattered rock overlying the limestone bedrock. This type of terrain unfortunately is not similar to any of those studied at Churchill, but the fluctuations in temperature through the year follow similar curves of change.

Description of the Churchill environment

Topographic and vegetation features

The Churchill area supplies many of the major terrain types of the North American tundra and the boreal forest (Beckel, Law and Irvine, 1954). From Cape Merry eastward to Half Way Point along the north shore for a distance of about 15 miles there occurs a series of rough quartzite ridges, which ridges range in height from 25 to 100 feet above sea level. To the south and east of these ridges, the country presents a picture of a relatively

flat plateau dissected occasionally by small streams and old beaches of sand or gravel. A large proportion, perhaps 75 per cent of this plateau, is composed of sedge swamps and lakes of varying shapes and sizes. The remaining 25 per cent is made up of dry heath uplands and tussock or hummock muskeg.

The vegetation on the whole is that of the boreal forest with frequent representatives of the tundra population. Scattered clumps of spruce occur along the quartzite ridges and attain heights of up to 30 feet where they are relatively sheltered by the ridge from the prevailing northwesterly winds. On the open exposed portions of the ridge, the trees are stunted; their living branches are densest on their southeast side away from the wind, and very dense at their base where they are protected by snow from the drying effect of the winter winds. About 4 miles south of the Bay, the forest begins to thicken. The trees which are for the most part larch, and white and black spruce, are small and distorted here in the transition area. They are gradually replaced by taller members of the species as the distance between them and the Bay is increased. Occasional dense stands of tall spruce and larch are encountered along the margin of the forest zone, as, for example, along the small gravel ridges just east of the railway and west of the southern tip of the north-south runway (Fig. 1).

Table II

Climatic summaries for Churchill, Manitoba
(Canada, Department of Transport, 1947)

Month	Daily mean temp. °C	°F	Average snowfall (in.)	Average precipitation (in.)	Average monthly rainfall (in.)	Average no. of days with measurable ppn. of any sort
Jan.	—28	—19	4.8	0.48	0.00	5
Feb.	—27	—17	6.1	0.61	0.00	6
Mar.	—21	—6	8.5	0.87	0.02	6
Apr.	—10	14	7.7	0.89	0.12	6
May	—1	30	1.8	0.93	0.75	7
June	6	43	1.4	1.85	1.71	9
July	12	54	0.00	2.19	2.19	10
Aug.	11	52	Trace	2.69	2.69	12
Sept.	6	42	1.7	2.33	2.16	11
Oct.	—3	27	8.0	1.43	0.63	12
Nov.	—14	6	10.3	1.03	0.00	9
Dec.	—24	—11	6.6	0.66	0.00	8
Annual	—8	18	56.9	15.96	10.17	101
Years observed	30	30	30	30	30	10

Geology

Williams (1948, page 40) has described the rock outcrops characteristic of the Churchill area as quartzite "made up of fairly well rounded quartz grains, with a small amount of interstitial sericite . . . the quartz content of the rock is about 70%, half of coarse and half of fine grains. The sericite content is about 30% . . . . The white dolomites are extensively represented on both sides of the mouth of the Churchill river . . . . Out at Landing or Farnworth Lake, some seven miles to the south, piles of dolomite slabs are common." He suggests that the presence of particular

fossils in some of the limestone formations indicates Silurian and Ordovician elements.

Soil

There is no "soil" in the Churchill area, according to the commonly accepted conception of a "developed soil". A layer ranging from 0 to 24 inches of peat is found above a subsoil of gravel, sand, or clay, or combination of these. The peat may vary from fine black and well-decomposed to coarse, fibrous material in which the plants from which it has been derived are clearly recognizable. The pH values of the peat, which range from 6.0 to 7.5, reflect the large proportion of limestone gravel and sand in the subsoil. The water content of the soil has not been ascertained, but generally speaking, may be said to be very dry on the crests of ridges and hummocks and saturated or near saturated elsewhere.

Climate

Table II summarizes the pertinent climatic data for the Churchill region as averaged over a ten- to thirty-year period. With a mean annual temperature of 18° F, perennially frozen ground would be expected, and is found, in the area. The depth of the active layer above it (that layer subject to seasonal freeze and thaw) varies from area to area depending upon soil type, soil moisture conditions, plant cover, and winter snow cover. The thickness of the perennially frozen ground has been found (Johnston, 1930) to be at least 115 feet. The high water table which results from the presence of the perennially frozen ground produces a marsh and lake-filled country not otherwise to be expected with the low annual precipitation of 16 inches.

Method

In the fall of 1950 a research program was initiated for the study of temperatures of the active layer of soil in the Fort Churchill, Manitoba region. The position (Fig. 1) of each of the stations selected was determined initially by the combination of needs of three projects under way at the time at the Defence Research Northern Laboratory. Some were placed in or near ponds which were being studied as habitats of particular colonies of mosquito larvae or other aquatic invertebrates; others were located on higher drier ground in an attempt to obtain representative samples of the drier terrain types, such as have already been described for the area. (Beckel, Law and Irvine, 1954). A total of thirty-one stations was established in the vicinity of Fort Churchill. Of these, twenty-two were located in or near pools or swamps; seven were located on dry terrain, and two (numbers 30 and 9) were accidentally destroyed by caribou during the first spring. In 1951, another twelve stations were added in order to more adequately represent the drier terrain of the region within the camp as well as outside it. Of these, numbers 34, 35 and 43 were the only ones located outside the camp, hence are the only ones discussed further in this paper.

During the first two years, and during the winter seasons in particular, it became obvious that the number of stations in the field was too many to service and to observe properly with the equipment and staff available. As

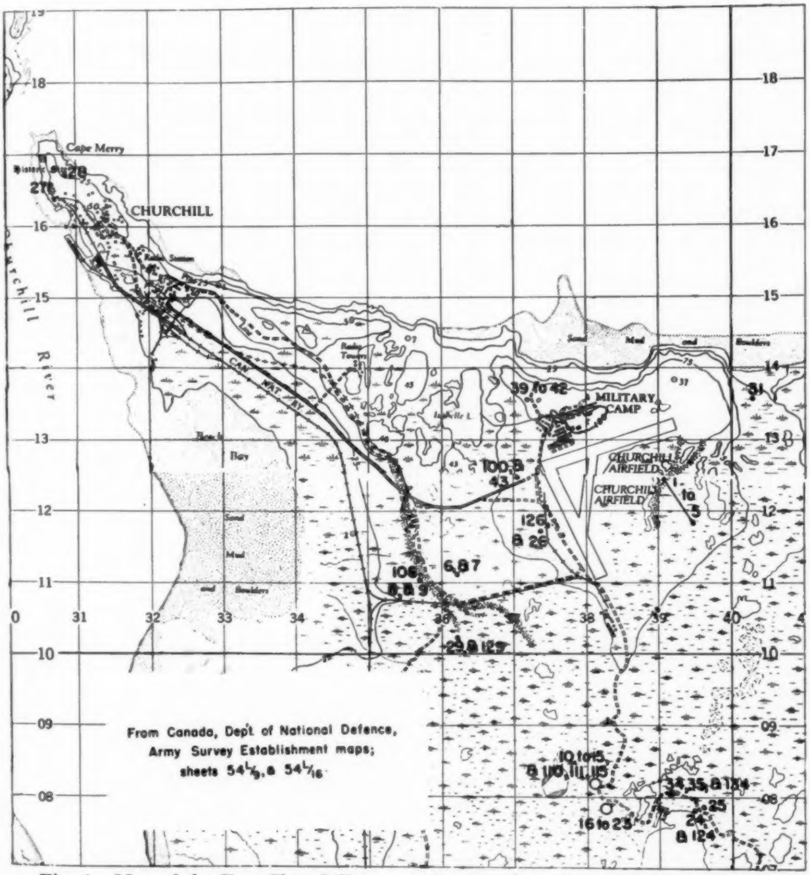

Fig. 1. Map of the Fort Churchill area, indicating the soil temperature stations.

a result, in the fall of 1952 seventeen stations (numbers 8, 10, 11, 12, 15, 16, 23, 24, 25, 26, 29, 34, 35, 36, 41, and 42) were selected as representative for continued observations and the remainder were discarded. In the fall of 1953, six further stations were established to measure snow depth and temperature as well as active layer temperatures. These new stations were located adjacent to stations 26, 34, and 43 (number 43 had been broken by an oversnow vehicle during the winter of 1951 and was not subsequently replaced), 11, 8 and 15; these new stations were designated 126, 134, 100, 111, 108, and 115 respectively. These six new stations, in addition to the following, were observed regularly during the next year; numbers 12, 15, 26, 8, 29, 24, 34, 35, 23, 10, and 11. The positions of the stations studied from 1950 until 1954 are indicated on the map (Fig. 1).

Table III lists the thickness of the active layer at each station as determined in August of 1951 and three years later, in August of 1954. The type of terrain on which each station was located is also listed.

Table III

Thickness of active layer at soil temperature stations, August, 1951, and August, 1954

(Asterisk indicates depth measured by probing: lack of asterisk indicates depth determined by digging)

Description of terrain type	Site number	Frost depth (inches) Aug. 21 to 27 1951	Frost depth (inches) Aug. 23 to 25 1954	Water level (above or below surface)
A. HIGH DRY TERRAIN:				
low beach ridge (crest)	4	25	39*	—18″
low beach ridge (base)	54*	54*	35*	—36″
hummock	27	24	34*	not above frost level
mound	12	22	38*	not above frost level
mound	18	59*	78*	—34″
foot of gravel ridge	26	96*	96+*	—24″
foot of gravel ridge	126	—	96+*	—24″
sand beach	31	58	—	not above frost level
heath plateau scraped bare of vegetation	34	30*	80*	—
heath plateau	134	—	34*	—
heath plateau scraped bare of vegetation then planted to lawn grass	35	30*	95*	—
heath plateau	43	56*	—	—25″
heath plateau	100	52*	54*	—25″
B. WET TERRAIN:				
edge of pool	1	52*	—	0 to 6″
edge of pool	2	52	51*	0 to 6″
middle of pool	10	84+*	92+*	0 to 6″
edge of pool	11	60*	86+*	—1 to —7″
edge of pool	111	—	86+*	—1 to —7″
middle of pool	16	84+*	90+*	6 to 12″
small hummock	21	84+*	—	—
middle of small lake	3	43*	—	0 to 6″
middle of sedge-lined pool	6	39*	43*	—30″
sedge swamp	8	64*	64*	4 to 10″
sedge swamp	108	—	64*	4 to 10″
sedge-lined pool	9	56*	—	4 to 8″
sedge swamp	13	65*	—	4 to 10″
edge of pool	14	44*	83+*	0 to 6″
sedge swamp	15	58+*	87+*	0 to 12″
sedge swamp	115	—	87+*	0 to 12″
edge small pool	17	51*	—	—0 to —6″
edge small pool	20	62*	—	—3 to —7″
small dried pool	22	60*	—	—3 to —7″
small pool	23	67*	82*	0 to 6″
edge quaking sedge swamp	24	78*	90+*	0 to 8″
small pool	25	84*	—	4 to 15″
pool on quartzite outcrop	27	solid rock bottom		0 to 24″
edge sedge swamp	28	48*	—	—
margin sedge swamp in woods	29	132*	132*	0 to 8″

The thickness of the active layer at each station was determined by probing with an iron rod, or, where possible, by digging; these measurements were obtained during the latter part of August when the active layer had reached its maximum depth of thaw. On the basis of these measurements, the depth to which soil measurements would be made was determined. At no station were temperatures of 0° C encountered throughout

the summer; it was thus obvious that the thermocouple placed at the greatest depth in the active layer was still above the upper limit of the perennially frozen ground despite our preliminary examination of the stations.

Limitations of space have made it necessary to select only four representative sites for illustration of the information collected during the four-year study period. These four stations are described in detail in Table IV; the soil temperature observations over the four-year period for each of the four stations are recorded graphically in Figures 5 to 8. Snow depth and its effect on snow and soil temperatures at all stations is discussed later in the paper.

Equipment

At each site, dowel stakes with regularly spaced copper-constantan thermocouples on them were installed in the ground (Fig. 2). Leads from each couple were connected to a plug. This installation was permanent and e.m.f.'s could be read at regular time intervals by means of a field potentiometer similar to that described by Lytle (1954). That used for our research differed from that described by Lytle in our use of a Rubicon pointerlite galvanometer with a range of $-50°$ C to $+50°$, and our use of a copper rather than a copper-constantan plug. The e.m.f.'s were then converted to °C by means of conversion tables (Am. I. of Physics, 1941). Most previous soil temperature research has utilized solid thermometers and thermographs, but they are less convenient to use under winter conditions and require greater disturbance of the natural soil conditions. Copper-constantan thermocouples have been found by us and by Weaver and Clements (1929), Bouyoucos (1913) and Diebold (1937) to be thoroughly reliable; the combined possible error due to differences between thermocouples and to variation in potentiometer readings is negligible (Lytle, 1954).

At each station a "dummy" dowling stake was first hammered into the ground to clear the way for the stake with the thermocouples on it; the thermocouple bearing stake was then hammered into place and marked by a post bearing its station number and a flag to make it easier to locate during the winter months. Field installations for reading snow temperatures (Fig. 2) were installed in the fall of 1953. Preliminary field trials indicated that considerably less disturbance of the soil occurred when a stake with copper-constantan couples attached (Fig. 2) was hammered into the ground than when the method of previous workers (Diebold, 1937) of excavating soil, installing of couples at set levels, and re-filling of excavation, was used.

Procedure

During the first year soil temperature readings were made on the average of once every five weeks. During the second season, as quirks in field and recording equipment were ironed out, it was possible to increase the frequency of readings until, during the final season, they were made once every two weeks at the minimum. Concurrently with the soil temperatures, snow and water depth measurements were made at each site from November, 1951 until 1954. Before 1953, snow temperatures were recorded

Table IV

Description of stations for soil temperature readings

(Asterisk indicates frost depth measurements made by probing: depths indicated without an asterisk represent measurements ascertained by digging)

Site no.	Frost depth (inches) Aug. 21-27 1951	Frost depth (inches) Aug. 23-25 1954	Soil profile		Position of site and vegetal cover	Water level (above or below the surface)
12	22	38*	0—2″ 2—8″ 8—22″ 22″	dry lichen moss mat black fibrous peat gravel-clay, with occasional limestone plates frost level	on high dry mound in thinly forested area; 5′ above swamp level Primary species: *Cladonia rangiferina* Secondary species: *Ledum groenlandicum* *Picea mariana* *Empetrum nigrum* *Vaccinium vitis-idaea var. minus* *Rubus chamaemorus*	not above frost level
35	30	95*	0—10″ 10—30″ 30″	black fibrous peat with occasional limestone plates gravel clay mix frost level	High dry heath plateau just north of Farnworth Lake scraped bare of vegetation, then planted to lawn grass mix	not noted above frost level
8	64*	64*	0—8″ 8—?″ 64″	unconsolidated brown peat black muck, well decomposed apparent frost level	In small patch (6′ x 10′) of open water in sedge swamp Primary species: *Carex aquatilis* Secondary species: *Triglochin maritima* *Ranunoulus gmelinii* *Eriophorum angustifolium* *Arctagrostis latifolia*	4—10″
29	132*	132+*	0—8″ 8—132″	medium coarse black peat sandy with occasional gravel and boulders	Margin of heavily wooded spruce forest and sheltered sedge swamp region; deep soft snow in winter Primary species: *Carex limosa* *Scirpus hudsonianus* Secondary species: *Salix arctica* *Picea mariana* *Larix laricina* *Betula glandulosa* *Vaccinium uliginosum*	0—8″

at only such stations as had spare thermocouples above the surface of the ground or water; during the winter of 1953-4 snow temperature measurements were made each time the soil temperature readings were made for each station. In all cases, the temperatures were taken during the daytime.

Ambient air temperature records were obtained from the local Department of Transport Meteorological office and averaged over ten-day periods (Fig. 3). Solar radiation data (Fig. 4) collected at this laboratory (Blakely, 1954) have been graphed similarly. The changes in temperature gradient of the active layer at four typical sites are illustrated in Figures 5 to 8. The temperatures at all depths for which data were collected are not indicated in the figures; rather enough to give a picture of temperature gradient have been selected and graphed. In all cases, temperatures for the upper and

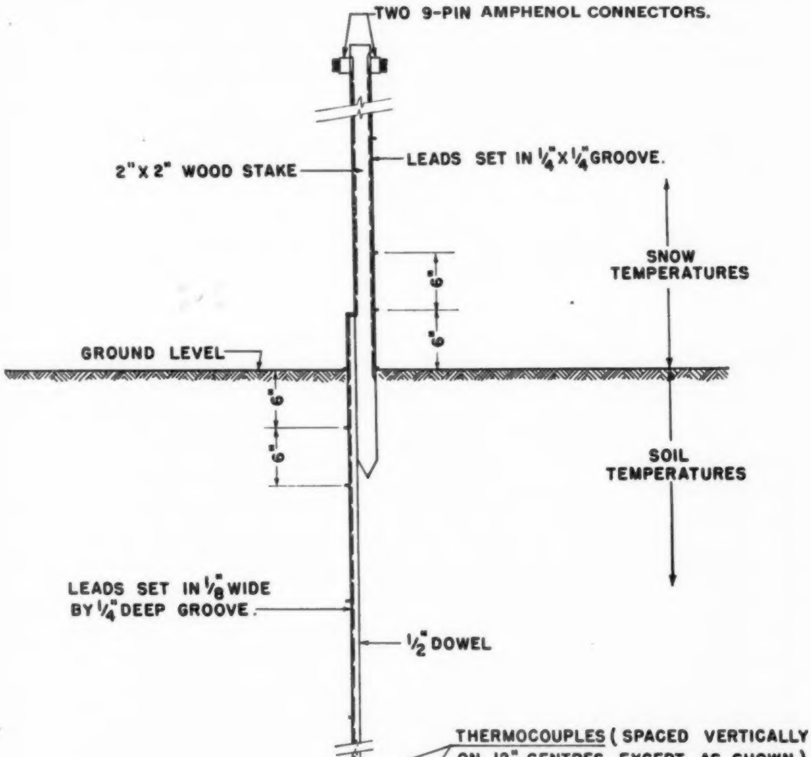

Fig. 2. Field thermocouple installations. Typical test site.

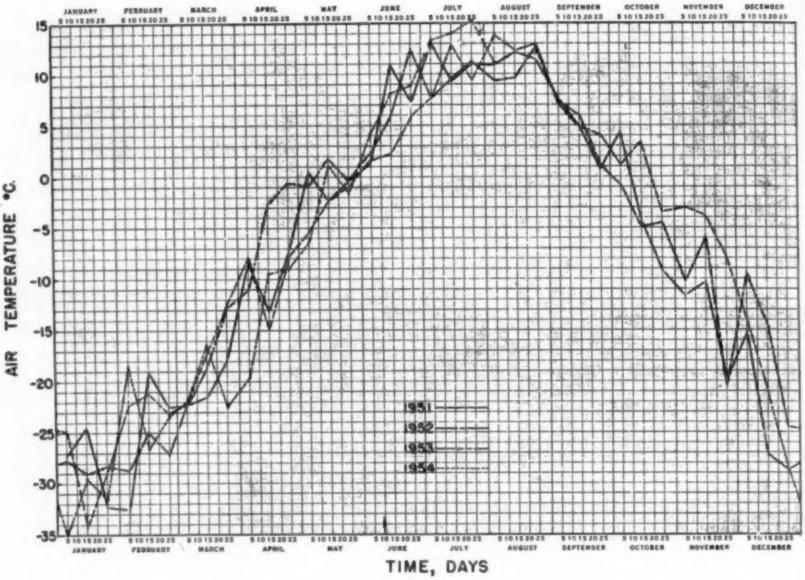

Fig. 3. Ambient air temperatures with time. Ten-day averages compiled from data collected by Meteorological Division, Department of Transport, Churchill, Manitoba.

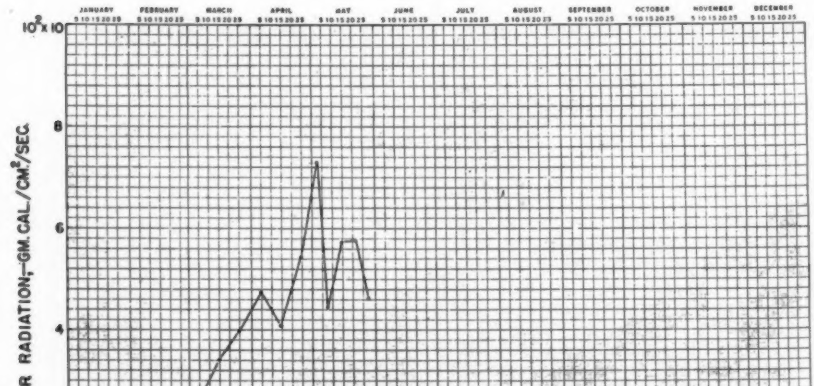

Fig. 4. Solar radiation with time, for January to May, 1954.

lower depths and for one or more intermediate depths are indicated. It was not possible to thrust the stakes into the ground to the full depth of the active layer, but the depth of the lowest recording couple is indicated for each site in the figures. Pertinent data for the remaining sites are included where applicable in other sections of this paper.

Results and discussion

Factors affecting soil temperature

Climatic factors. Ambient air temperature (Fig. 3) and solar radiation (Fig. 4) follow, generally speaking, the same curve of rise and fall over the period during which data are available for the latter. Over this period the soil temperature curves follow more closely in form that of the ambient air temperature than that of solar radiation. Comparison of the soil temperature curves (Figs. 5-8) with ambient air temperature (Fig. 3) indicates that during the winter the majority of stations lag behind ambient air temperatures in reaching extremes (see also Table V). Those stations which reach their coldest extreme at the surface before the ambient air temperature reaches its lowest extreme, are located in sedge swamps and early in the winter are covered by a thick insulating layer of snow. For the remainder of the stations the surface soil reaches its lowest extreme from 3 to 50 days after the ambient air reaches its lowest extreme. No significant difference is noted between dry and wet stations or hard and soft snow. With medium and lowest soil depths, however, the extreme lows in temperature are reached from 12 to 83 days after that of the ambient air temperature. Generally, the earliest lows are reached in the dry stations and the latest lows in the soil of the wet stations.

In the daytime, during the summer, the upper few inches of soil reach their maximum temperature in wet and dry areas 13 to 67 days before the ambient air temperature does. The fact that this soil temperature is recorded during the daylight hours and that the record does not represent an average through the day, accounts for this seeming anomaly. The expected lag, as noted by Cook (1955), was recorded for depths below the level affected by diurnal variation in the temperature of the ambient air. The lower soil of the active layer was noted to reach its maximum temperature 20 to 50 days after the maximum ambient air temperature was reached. Two exceptions to this occurred, one at a dry site (35) and one at a wet site (15); an explanation for these exceptions has not as yet been found. Of the rest which reached their extremes after that of the ambient air temperature, wet and dry stations were among the early and middle extremes; the two very late extremes were reached at the lowest depths of wet stations (sites 8 and 29). The overall picture seems to be that the dry peat overlying the mineral soil of the dry stations provides insulation against the continued change in temperature which takes place in the saturated peat and mineral soil of the wet stations. The maximum depth of thaw in terms of dates

Table V

Comparison of extreme temperatures recorded for upper and lower depths of the active layer for selected stations, and of extremes for ambient air temperatures averaged over ten-day periods

Station no.	Depth in. of soil	1951				1952				1953				1954			
		Temp. °C	Date	Temp. °C	Date	Temp. °C	Date	Temp. °C	Date	Temp. °C	Date	Temp. °C	Date	Temp. °C	Date	Temp. °C	Date
8	2	— 9.5	Mar. 2	+11.0	Aug. 17	—15.0	Feb. 21	+ 8.5	Aug. 12	—8.5	Mar. 4						
	55	— 6.5	Apr. 25	0.0	July 24	— 9.0	Mar. 19	+10.0	Oct. 16	—4.0	Mar. 17						
108	0													—13.0	Jan. 28	+13.0	July 19
	54													— 6.5	Mar. 31		
10	8					— 1.0	Mar. 8	+ 6.5	Aug. 12	—1.0	Jan. 4	8.0	Aug. 18	— 3.5	Jan. 29		
	30					0.0	Nov. 1	+ 4.0	Sept. 13	—1.0	Jan. 4	5.0	Sept. 8	— 1.0	Apr. 1		
110	0													—11.0	Jan. 29	+19.0	July 27
	60													— 0.5	Apr. 1		
11a	0					— 2.5	Jan. 21	+17.0	July 16			21.0	Aug. 18	— 4.5	Jan. 29	+23.0	July 19
	66					— 1.0	Apr. 8	+ 1.5	Sept. 13	— 1.0	Jan. 4	3.5	July 21	0.0	Nov. 3		
111	0													to —1.0 — 7.0	Jan. 29	+22.0	July 19
	60													0.0	Dec. 17		
12	1	— 7.0	Jan. 9	+16.5	Aug. 15	— 8.0	Feb. 5	+15.0	July 16	—8.0	Feb. 10	23.0	July 21	— 9.0	Jan. 29	+22.5	July 6
	21	— 4.0	Feb. 26	+ 0.5	June 12	— 4.0	Mar. 7	+ 1.0	Sept. 13	—4.0	Feb. 10	2.5	Aug. 3	— 4.5	Apr. 1		
112	0													—21.0	Jan. 29	+24.5	July 5
	22													— 5.5	Apr. 1		
15	9	—15.	Jan. 5	+11.5	Aug. 24	— 1.5	Dec. 18	+12.0	July 16								
	45	— 0.5	Jan. 5	+ 5.0	Aug. 28	— 0.5	Dec. 18	+ 5.5	Aug. 12	—1.0	Jan. 4						
115	1													— 1.5	Jan. 17	+10.5	July 26
	53													0.0	Feb. 13		

Table V (cont'd)

Table V (cont'd)

Station no.	Depth in. of soil	1951 Temp. °C	Date	Temp. °C	Date	1952 Temp. °C	Date	Temp. °C	Date	1953 Temp. °C	Date	Temp. °C	Date	1954 Temp. °C	Date	Temp. °C	Date
23	6					−1.0	Feb. 21	7.0	Aug. 12	0.0	Dec. 5	9.5	July 15	−7.5	Jan. 15	9.5	July 27
	60					0.0	Feb. 5	4.5	Sept. 13	0.0	Mar. 16	6.5	Sept. 23	−4.0	Feb. 12		
123	0.5															19.0	July 19
24	0					−3.0	Feb. 5	15.0	June 19	−0.5	Jan. 4	17.0	Aug. 21	−1.0	Dec. 29	14.0	July 27
	72					−1.0	Mar. 21	12.5	Sept. 12	+0.5	Jan. 4	8.5	Aug. 21	−1.0	Mar. 16		
124	1													−1.5	Mar. 31	12.5	July 27
	73													+0.5	Mar. 31		
26	0							25.0	July 21	−1.0	Mar. 3	25.0	Aug. 21			26.5	July 7
	84					−1.0	Jan. 26	3.5	Sept. 13	0.0	Mar. 3	5.5	Sept. 11				
126	0													−15.0	Dec. 30	26.5	July 20
	96													0.0	Mar. 18		
29	0					−4.0	Mar. 7	18.5	July 21	−0.5	Feb. 4	20.5	July 8	−4.0	Jan. 28	19.0	June 29
	112					0.0	May 27	6.0	Oct. 16	+0.5	Apr. 26	5.5	Sept. 10	+1.0	Feb. 27		
129	0													−3.0	Jan. 28	19.5	July 19
	120													+1.0	Feb. 27		
34	0					−17.0	Jan. 17	16.0	July 21	−9.5	Mar. 2	24.5	Aug. 4	−29.0	Jan. 15	24.5	July 19
	24					−16.5	Mar. 6	6.0	Sept. 13	−6.3	Feb. 10	7.0	Sept. 10	−13.5	Jan. 29		
134	0													−26.0	Jan. 29	27.0	July 19
	30													−14.0	Jan. 29		
35	0					−23.0	Jan. 17	14.0	July 21	−11.0	Jan. 4	25.0	Aug. 4	−34.0	Jan. 15	21.5	July 19
	24					−18.5	Mar. 7	7.0	Aug. 11	−6.5	Mar. 16	7.5	Aug. 4	−13.5	Mar. 31		
100	0													−27.5	Jan. 29	21.0	July 6
	42													−13.5	Feb. 26		
Ambient air		**−32.5**	**Feb. 5**	**12.2**	**Aug. 15**	**−29.0**	**Jan. 15**	**12.8**	**Aug. 25**	**−34.2**	**Jan. 15**	**13.8**	**Aug. 5**	**−35.0**	**Jan. 5**	**15.2**	**July 25**

generally takes place between the middle of August and the middle of October; the average date is September 15.

The effect of change in ambient air temperature on the soil was well illustrated in March of 1954 when a sharp drop of 6° C in air temperature (Fig. 3) around March 20 was followed by a drop in soil temperatures in the March 31 readings (Figs. 5-8). The snow was wetter at this time than is the case for the winter months, hence was a better conductor, and the drop in temperature was reflected at greater depths in the soil than could otherwise be expected.

Discrepancies in the 1951 and 1954 frost-level measurements (Tables III and IV) in cases other than sites 34 and 35 may be attributable to the extraordinarily warm and dry summer of 1954. As the water level in the ponds decreased, the temperature of the water increased rapidly during the day, and with it, that of the saturated soil below. Ultimately, all but the deeper pools (stations 8, 108, and 24 and 124) were devoid of standing water. The surface soil here, however, as in the case of the "high dry" stations, remained damp despite the comparatively dry summer. In spite of the apparently higher insulating capacity of the peat that is merely damp as compared with peat that is saturated (such a difference in insulating capacity is indicated by the fact that the frost level is higher under damp peat than under saturated peat), the frost level still receded with the added number of hot days. Frost level data collected during August of 1952 and 1953 could have helped substantiate this.

Temperature Inversion with Depth (Figs. 5-8; Tables V-VI). The temperature inversion due to a temperature lag as recorded in temperate climates is observable here with the temperature curves systematically lagging as the depth increases. In the fall, for example, the soil reaches 0° C at successively later dates at successively lower depths. But in that region of the active layer immediately above the frozen ground the temperature reaches 0° C before the middle of the active layer does, though later than the upper few inches.

Table VI lists the dates at which the surface of the soil, the soil at a 12-inch depth, and the lower stratum of the active layer reach 0° C in the spring and in the fall. Generally the lower layer freezes or thaws later than the upper by as much as a week or a hundred days. At a constant depth of 12 inches the lag varies from station to station and, even at a particular station, from year to year. Occasionally in the spring the soil at this depth or even lower may reach 0° C before the surface does. This is probably a function of "warming" from below. None of the stations reached the level of the perennially frozen ground, and therefore, no measurements were made of its temperature. But the data collected at the various stations, including those used for purposes of illustration in this paper (numbers 8, 12, 35, and 29), indicate that the soil at the surface of the perennially frozen ground or just above it does not necessarily freeze during the winter, and therefore could exert a warming effect on the layers above it. A longer lag of 10 to 40 days is found both spring and fall in areas where the soil is relatively dry (sites 34, 35, 134, 100) and thus, a better insulator. This holds

Table VI

Comparison of dates at which ambient air, surface, 12-inch depth, and lower portion of active layer reach 0°C

Station no.	Depth in.	1951		1952		1953		1954
		Spring	Fall	Spring	Fall	Spring	Fall	Spring
8	2	June 8	Nov. 19	May 8	Nov. 4			
	15	June 20	Nov. 24	June 5	Nov. 4			
	55	July 24	Nov. 19	Oct. 16	Oct. 16			
108	0						Nov. 4	May 29
	12						Dec. 2	June 11
	54						Dec. 18	July 28
10	8	April 26	Oct. 31	Apr. 23	Dec. 5	Mar. 16	Dec. 1	May 13
	30	all winter	Oct. 31	all winter	Nov. 18	Mar. 16	Dec. 17	May 10
110	0						Nov. 1	May 10
	12						Dec. 17	May 17
	60						Jan. 29	Apr. 26
11a	0			Apr. 23	Oct. 15		Nov. 1	May 10
	12			Apr. 23	Jan. 4	May 23	Nov. 3	May 10
	66			Apr. 23	Oct. 15	all winter	Nov. 3	all winter
111	0						Nov. 3	May 13
	12						Dec. 17	May 13
	60						Dec. 17	all winter
12	1	May 15	Oct. 2	Apr. 22	Oct. 15	May 20	Nov. 1	May 8
	11	May 15	Nov. 15	Apr. 23	Oct. 15	June 20	Nov. 17	May 15
	21	May 15	all summer	Apr. 23	Oct. 15	July 8	Nov. 17	May 17
112	0						Oct. 26	May 13
	12						Nov. 17	May 18
	22						Dec. 17	May 20
15	9	May 15	Nov. 16	Apr. 23	Nov. 4	May 20		
	45	Feb. 26	Dec. 12	Feb. 5	Dec. 13	May 20		
115	1						Nov. 3	Apr. 28
	13						Feb. 13	Apr. 1
	53						Feb. 13	all winter
23	6			Apr. 23	Dec. 5	Apr. 15	Dec. 1	Apr. 26
	60			all winter	Mar. 15	all winter	Dec. 28	Feb. 25
123	0.5						Dec. 1	May 10
	12.5							May 10
	61.5							May 13
24	0			Apr. 23	Dec. 26	Mar. 10	Dec. 21	Apr. 26
	12			Apr. 23	Jan. 4	Jan. 4	Dec. 21	Apr. 26
	72			Apr. 23	above freezing all winter		Dec. 24	Apr. 13
124	1						Dec. 1	May 13
	13						Feb. 26	June 15
	73						above freezing all winter	

Table VI (cont'd)

Station no.	Depth in.	1951 Spring	1951 Fall	1952 Spring	1952 Fall	1953 Spring	1953 Fall	1954 Spring
26	0			May 27	Nov. 4	June 1	Nov. 17	
	12			May 8	Dec. 6	June 1	Dec. 8	May 18
	84			Feb. 21	above freezing all winter		Mar. 18	Mar. 18
126	0						Nov. 9	June 15
	12						Dec. 4	May 28
	96						Mar. 18	all summer
29	0			Apr. 24	Dec. 6	Mar. 31	Nov. 4	
	8			Apr. 24	Dec. 6	all winter	Dec. 18	May 12
	112			all winter	above 0° all winter	all winter	above 0° all winter	
129	0						Dec. 1	May 4
	12						Dec. 20	May 11
	120						above 0° all winter	
34	0			Apr. 27	Oct. 13	May 20	Oct. 24	May 12
	12			May 27	Nov. 25	May 20	Nov. 24	May 20
	24			May 27	Dec. 5	June 1	Dec. 1	May 24
134	0						Oct. 22	May 10
	12						Dec. 3	June 4
	30						Dec. 17	June 21
35	0			Apr. 27	Oct. 8	May 24	Oct. 22	May 12
	12			May 7	Nov. 4	May 28	Nov. 24	May 26
	24			May 26	Dec. 17	May 31	Nov. 2	June 1
100	0						Nov. 7	May 9
	12						Nov. 17	June 9
	42						Nov. 17	Aug. 2
Ambient Air		**May 27**	**Oct. 10**	**May 8**	**Sept. 30**	**May 29**	**Oct. 20**	**May 12**

true not only for a temperature of 0° C, but for the low and high extremes of temperature occurring in the winter and the summer (Table V). Stations where standing water occurs, or where the soil is saturated, usually reach 0° C in the spring at all depths at about the same time, and often before the ambient air temperature reaches this average. The higher conductivity of water over that of damp, but not saturated, peat, offers an explanation for this. The better conductivity of sand as compared with that of peat also can help to explain the rapid warming of stations 26 and 126, where the water table is well below the surface of the ground. Stations 8 and 108 are in an open exposed swamp where a relatively thin mantle of hard snow collects. As a result the soil generally becomes much colder throughout, and freezes and thaws with the lower strata lagging behind the upper, much as in the higher, drier areas. In the fall on the other hand, the lag of the lower strata behind the upper in wet areas may vary within a range of from zero to

over a hundred days, the amount depending upon the depth to which the active layer extends, and upon the amount of snow cover to provide insulation. The effect of snow cover will be discussed in a later section.

Soil at or near the surface of the ground reaches 0° C in the spring sometimes as early as 80 days before, or as late as 19 days after the ambient air temperature reaches 0°C. These readings were taken during the daytime in all cases. The early extremes occur in areas where the soil is saturated or water covered (and often frozen at this time of year), and topped by a layer of soft snow of at least 12-inch depth. The snow is wet at this time of year, and this, combined with the frozen saturated soil, provides an excellent conductor for heat. The late extremes occur where the soil, whether dry or wet, is topped by a thick or thin layer of hard-packed snow. Under this snow the soil temperatures were lower during the winter months than was the case for the soil under soft snow. Hence, it appears that greater extremes of cold in this soil simply cause it to take longer to warm up in the spring. In the fall the soil reaches 0° C from 2 to 70 days after the ambient air does. The late extremes are found where the soil is under water and covered by a 10-or-more-inch thick insulating layer of snow. The early extremes occur in the open areas where little or no snow accumulates until late winter, and thus provides little insulation for the soil.

Extreme Temperatures of the Soil (Table V). The surface of the soil in the ponds and at the edges of ponds in the wooded areas where an ample layer of snow (over 15 inches) collects, reached temperatures through the winters of 1950-52 of +0.5° to —4.0° C. Little snow accumulated during the winter of 1953-4 until five or six weeks later than had normally been the case. As a result, the ground was more poorly insulated and the pond surfaces reached temperatures of —1.0° to —11.0° C. Stations 8 and 108, which normally have little snow cover, regularly reach temperatures of —8.0° to —15.0° C at their soil surfaces.

At the lowest soil levels at which temperatures were recorded, many stations in the swamp and pond areas in the forested zones rarely go below +0.5° to —1.0° C.

At the higher drier stations, much greater extremes in temperature at or near the surface are reached both winter and summer (Table V). In the non-forested region, temperatures at certain stations may reach —25° C. Where insulated by thick soft snow in the forest, the extremes are —7° to —9° C. The gradient quickly falls in areas such as 12 and 112 where a thick dry peat layer insulates the soil below, and where snow adds insulation during the winter months. At stations in the open with little snow for insulation, as for example, 34, 35, 134, and 100, the soil may reach temperatures of —14° C at the lowest depths (24 to 40 inches). The soil is damp enough that, when frozen, it offers little insulation without the assistance of snow.

In the summer, the heat penetration varies considerably, depending not only upon soil type and moisture content, but upon density of plant cover. In most cases the upper layers of soil reached their highest temperatures a

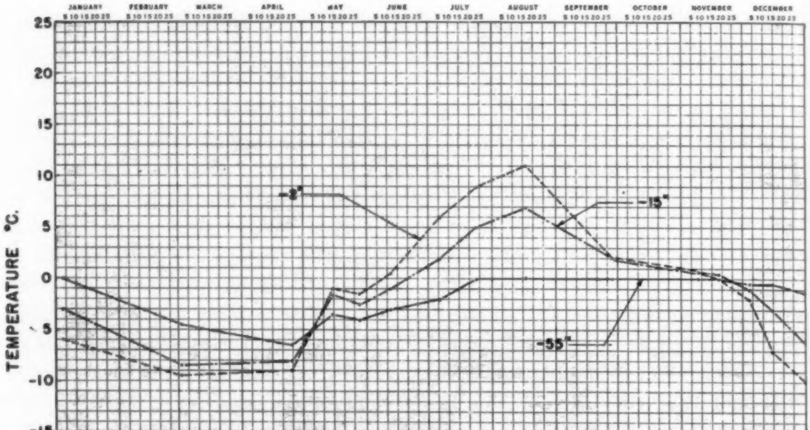

Fig. 5a. Soil temperature with time, for soil temperature station no. 8 for 1951.

month or two before the lower layers did. At station 8 in the summer of 1951 and station 11a in the summer of 1953, however, the lower layers were recorded to have reached their highest temperatures before the upper layers did. It is difficult to account for this except by assuming that plug connections were poor when the readings were made. The upper layer readings in most cases, except where they were 6 or more inches below the soil surface, reflect the temperature of the air during the morning or afternoon when they were recorded; thus a close correlation between them and air or lower soil temperatures cannot be expected, The soil at lower depths, however, is not as subject to change, according to hourly air temperature changes; the records of the temperature at this level then should be suitable for study. At two of the high dry stations, numbers 12 and 35, the temperature of soil at the lowest depths recorded reached its highest extreme earlier than was the case for the other dry stations or for the wet stations. The time of year for these two stations corresponded approximately with the time of year when the air reached its highest average temperature, while the remainder of the stations usually reached their highest temperatures at this depth a month or two later.

Density of plant cover. Plant cover can be divided roughly into two categories, forested and non-forested. The type of cover when considered alone appears to have little effect on the depth of the active layer. Where differences in type of cover affect the accumulation and retention of snow, marked differences in frost penetration occur. This will be discussed later. In the case of sites 34 and 35, the natural vegetal cover was bulldozed off.

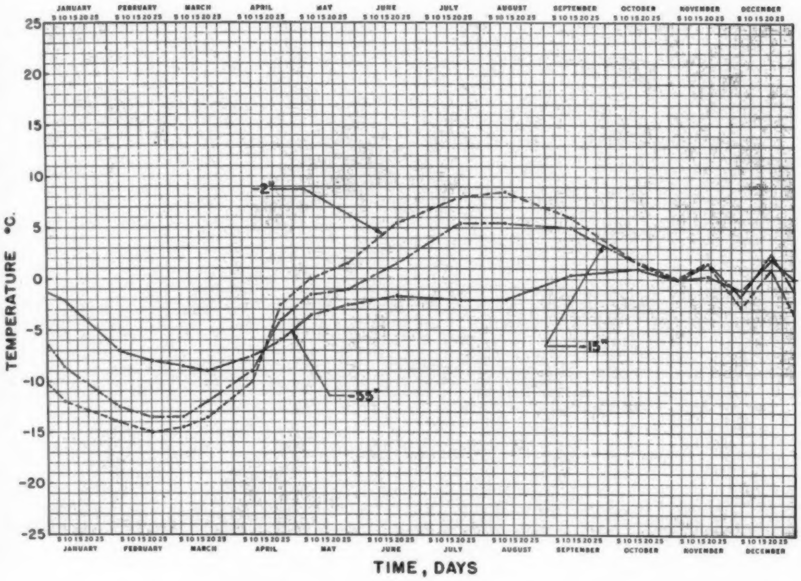

Fig. 5b. Soil temperature with time, for soil temperature station no. 8 for 1952.

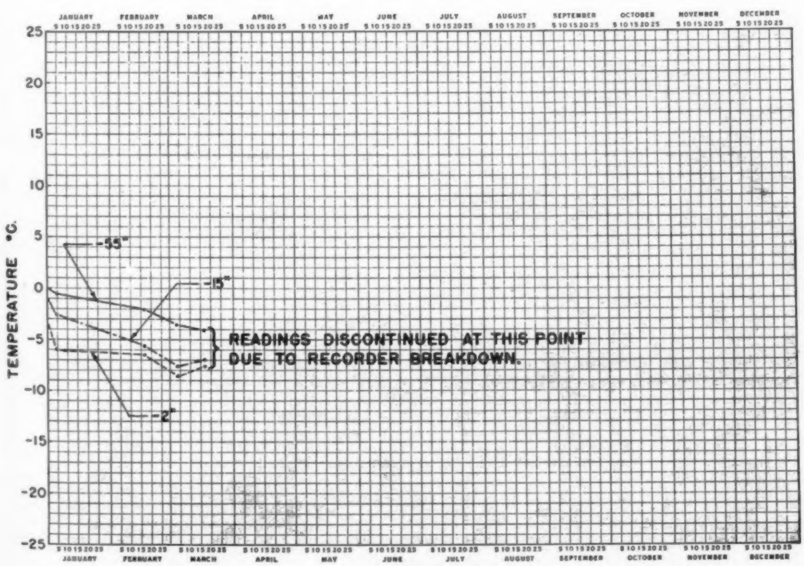

Fig. 5c. Soil temperature with time, for soil temperature station no. 8 for 1953.

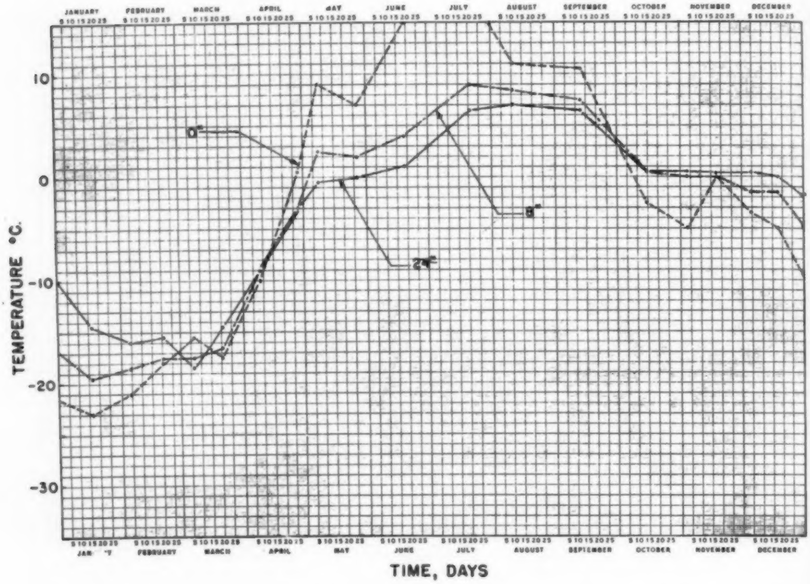

Fig. 6a. Soil temperature with time, for soil temperature station no. 35, for 1952.

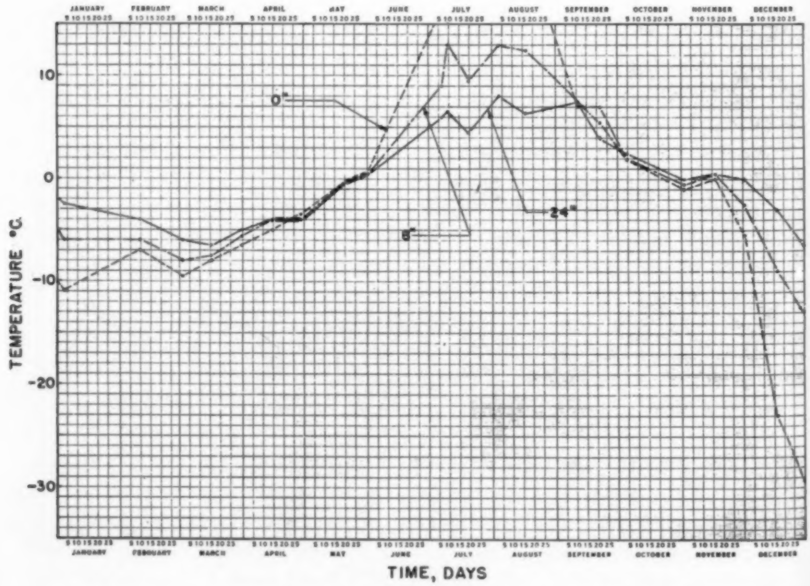

Fig. 6b. Soil temperature with time, for soil temperature station no. 35, for 1953.

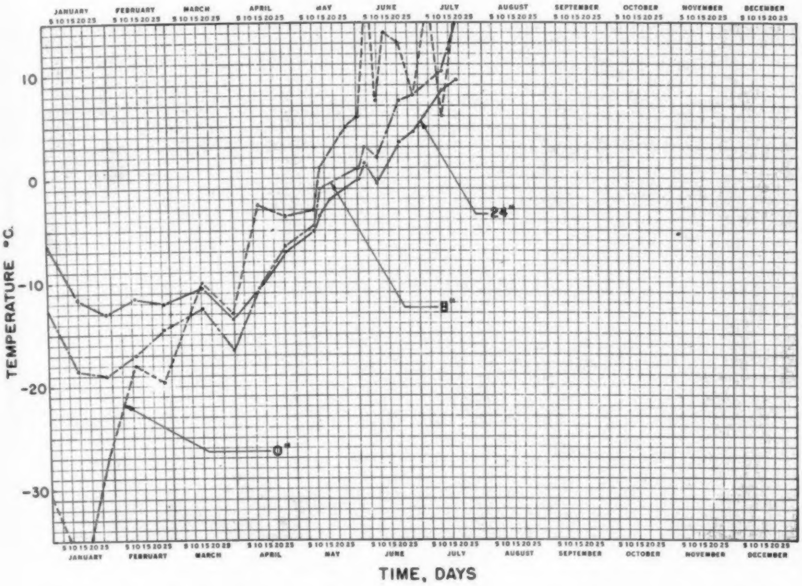

Fig. 6c. Soil temperature with time, for soil temperature station no. 35, for 1954.

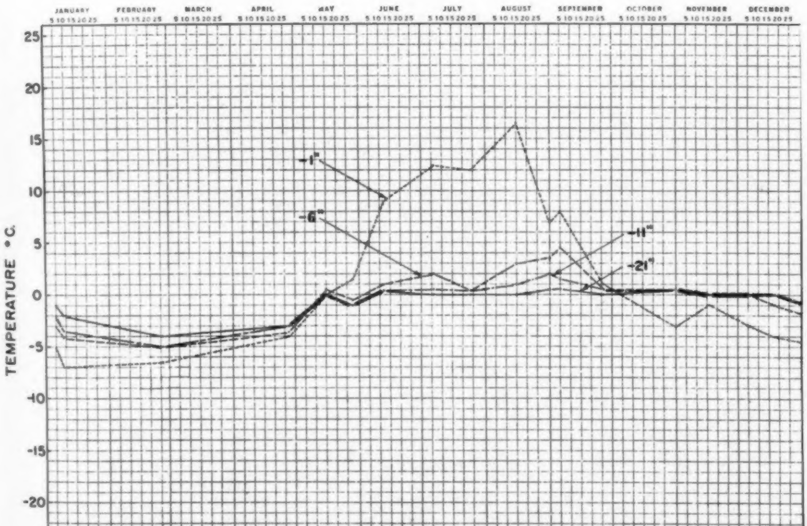

Fig. 7a. Soil temperature with time, for soil temperature station no. 12, for 1951.

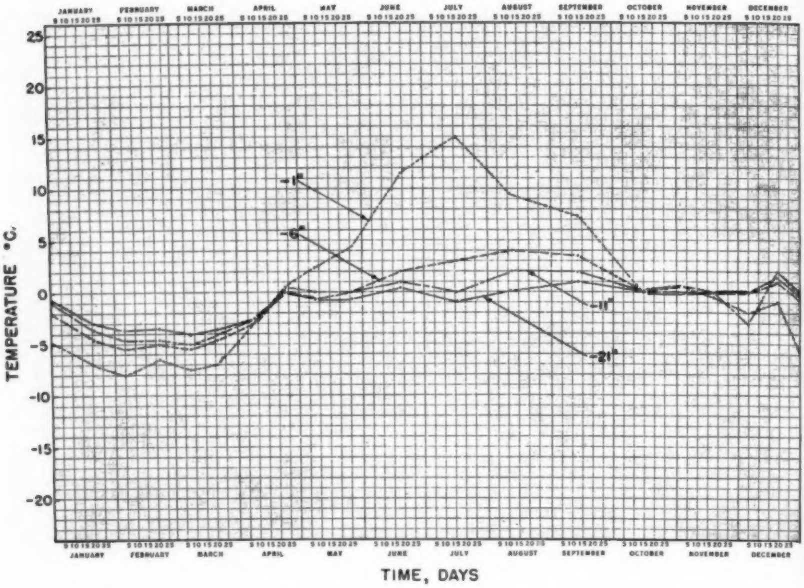

Fig. 7b. Soil temperature with time, for soil temperature station no. 12, for 1952.

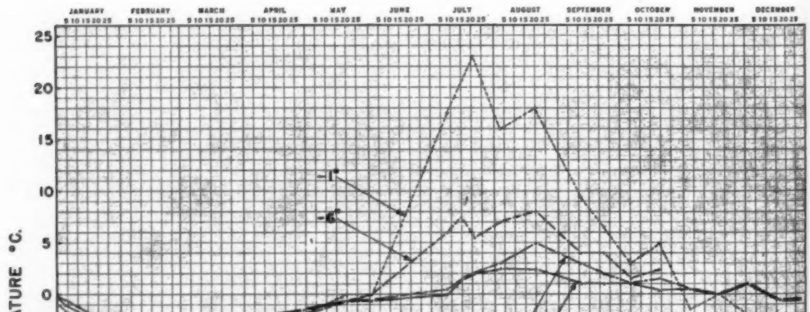

Fig. 7c. Soil temperature with time, for soil temperature station no. 12, for 1953.

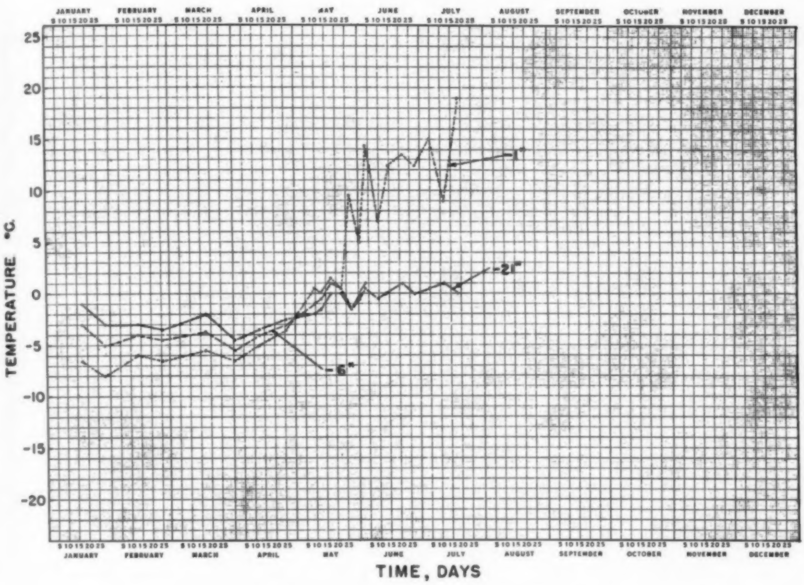

Fig. 7d. Soil temperature with time, for soil temperature station no. 12, for 1954.

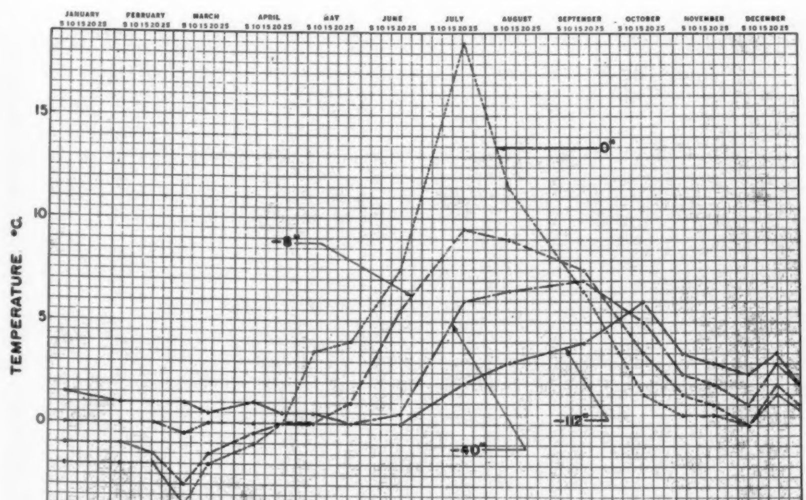

Fig. 8a. Soil temperature with time, for soil temperature station no. 29, for 1952.

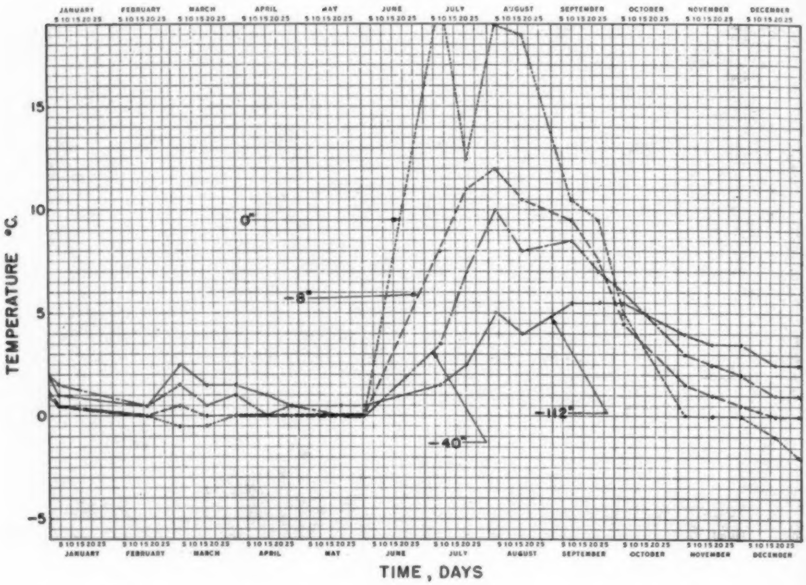

Fig. 8b. Soil temperature with time, for soil temperature station no. 29, for 1953.

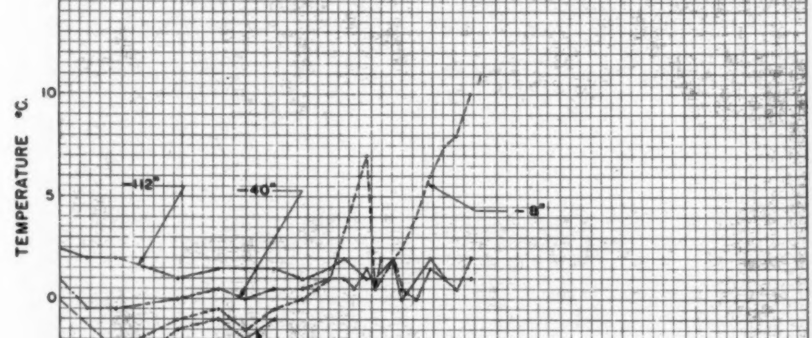

Fig. 8c. Soil temperature with time, for soil temperature station no. 29, for 1954.

Site 35 was sown to lawn grass and site 34 left bare; site 134 represents the same type of area but is undisturbed. Sites 34 and 35 had active layer depths of approximately 30 inches when first disturbed; by August of 1954, the frost level had receded to a depth of over 80 inches in these two, while that of site 134 measured 34 inches. The value of an undisturbed vegetal cover in preserving a relatively constant depth of active layer appears to be great.

Soil Type. Of the areas studied, those stations with a sandy soil (numbers 26, 126 at the sandy base of a clayey-gravel ridge; numbers 29 and 129 on the top of an old sandy beach) have an active layer noticeably deeper than those of other stations (Table III). Stations 26 and 126 are located on high ground, but have soil saturated from a depth of 24 inches below the surface down to the frost level, thereby increasing the conductivity of the sand. The drier area above apparently insulates the layers below sufficiently to produce the difference in frost depth between this site at +96 inches from that of sites 29 and 129 at +132 inches where 2-6 inches of standing water usually is present.

The remainder of the stations where the substratum consists of gravel-clay, sand-clay or other mixtures have frost levels which range from 34 to 90 inches below the soil surface. Within this group those stations in the higher drier undisturbed areas have frost levels ranging from 34 to 78 inches, while those in saturated soil or soil with standing water range from 43 to 92 inches. A broad overlap between these groups exists, probably due to the fact that the water table, even at the high dry stations, is at such a level usually that a relatively shallow layer of moist or dry, but not saturated, peat is present to act as insulation. In areas such as 134, 12 and 7 where the frost level occurs above the water table, the level of its occurrence is higher generally than where the water table occurs a few to several inches above it (Table III). With no precise data on the soil moisture content and exact frost level for the different soil types at varying depths through the season, even generalizations of this broad order are subject to error, and serve to point out the need for further study on this aspect of the problem.

Snow Cover. Normally the first snowfall comes during the last 10 days of September. Scattered snow flurries occur after this time, but not until the middle of October or the first week in November (Table VII), some 10 to 28 days after the average ambient air temperature reaches 0° C, is a measurable depth of snow to be found on the ground. In the flat, open tundra, hard snow may collect to a depth of 12 to 14 inches during the winter. In the forested areas, softer snow collects to depths sometimes reaching 50 or 60 inches.

In the lee of ridges or of trees lining a forest opening, soft or hard drifts of snow occur which may reach a depth of 60 to 130 inches, the hardness of the snow depending upon the degree and duration of exposure to wind. The snow gradually increases in depth through the winter until the end of March or mid-April when it reaches its maximum depth. After this, it melts rapidly and disappears from most areas by the end of May. This melt may take place as early as the middle of April, depending upon the average ambient air temperature and whether or not an April blizzard takes place. In years such as 1952, the daytime temperature may be very high, thus

Table VII

Dates of first and last measurable snow for the spring of 1951, spring and fall of 1952 and 1953, and fall of 1954 at soil temperature stations with dates when average (over 10-day periods) ambient air temperature reached 0° C.

Station no.	1951	1952		1953		1954
8	Oct. 20	Apr. 15	Oct. 15	May 31		
108					Nov. 5	May 12
10	Nov. 1	May 10	Oct. 15	June 15	Nov. 3	May 15
110					Nov. 3	May 20
11	Nov. 1	Apr. 30	Oct. 21	June 10	Nov. 3	May 27
111					Nov. 3	June 5
12	Nov. 5	Apr. 30	Oct. 15	June 10	Nov. 22	May 25
112					Nov. 4	May 22
15	Oct. 31	May 5	Oct. 20			
115					Nov. 4	May 25
23		May 1	Oct. 15	June 10	Nov. 4	May 20
123					Nov. 4	May 27
24		May 1	Oct. 15	June 15	Nov. 1	May 15
124					Nov. 1	May 20
26		June 10	Oct. 15	June 15	Nov. 5	June 15
126					Dec. 2	June 15
29		Apr. 30	Oct. 15	June 2	Nov. 4	May 20
129					Nov. 4	May 22
34		Apr. 20	Oct. 15	June 5	Nov. 20	May 15
134					Nov. 4	May 4
35		Apr. 20	Oct. 15	May 25	Nov. 4	May 13
100					Feb. 20	May 22
Ambient Air	**Oct. 10**	**May 8**	**Sept. 30**	**May 29**	**Oct. 20**	**May 12**

producing a rapid melt and an average ambient air temperature of not more than a few degrees below zero. The average weekly ambient air temperature did not reach 0° C until May 8, but the snow had disappeared from all but heavily drifted areas during the period April 15-May 5. During the following springs, the snow had not melted until much later in the year — May 25 to June 15 in 1953, and May 4 to June 5 in 1954. In 1953, the weekly-averaged, ambient air temperature reached 0° C on May 29; the snow had disappeared in a period ranging from 23 days before this date in some areas to as late as 24 days after this date. Those areas where early melt occurred in these years were in open exposed high areas where less snow collected during the winter.

The temperature of the soil at a particular depth may vary considerably from station to station at a particular time. An example of such a variance is shown in Figure 9 where the relation between depth of snow and temperature of soil at a 12-inch depth is shown for February of 1952, 1953 and 1954. By February, the majority of stations have reached their maximum coldness at a 12-inch depth. Some have begun to warm up again, but, on the average, it is the most stable month for this comparison. With increasing depth of snow, the insulation it affords (as indicated by the thermal gradient) also apparently increases; however, after 20 to 25 inches of snow, little change in insulating effect appears to take place. Other variables, however, may enter into the problem. Some of the stations have

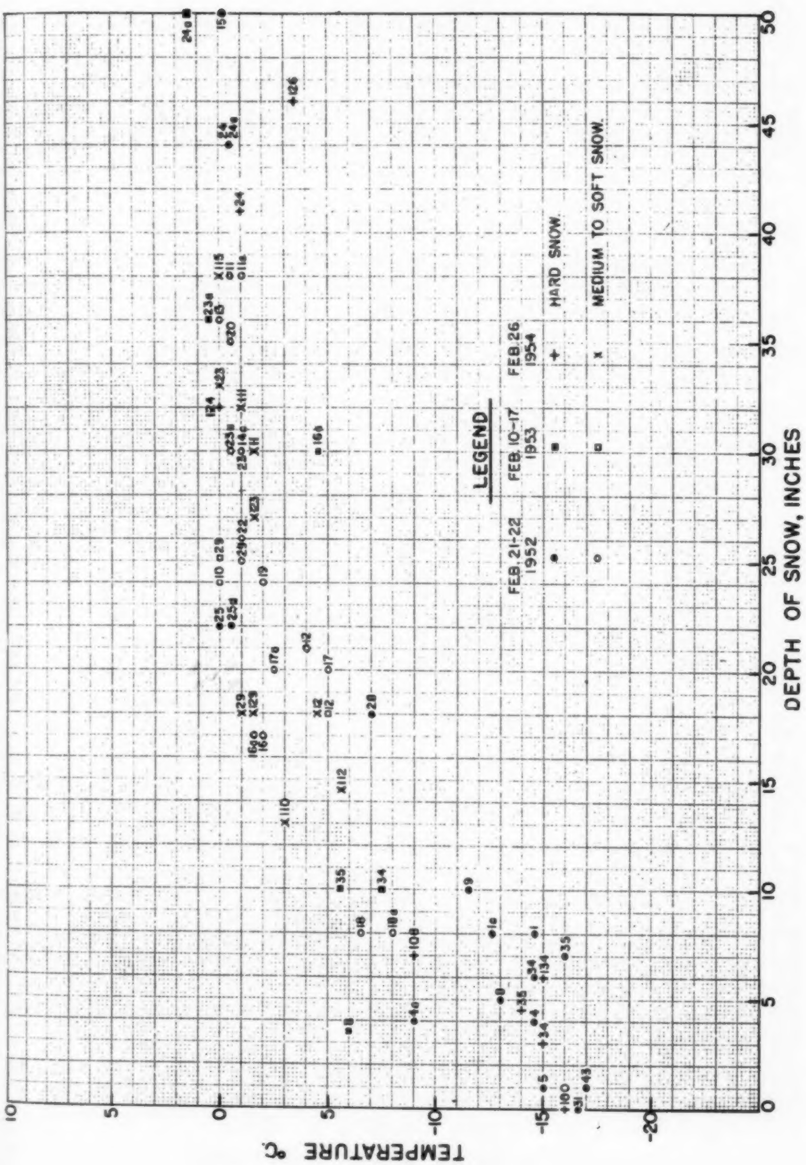

Fig. 9. Relation between snow depth, and soil temperature at 12-inch depth, at different stations.

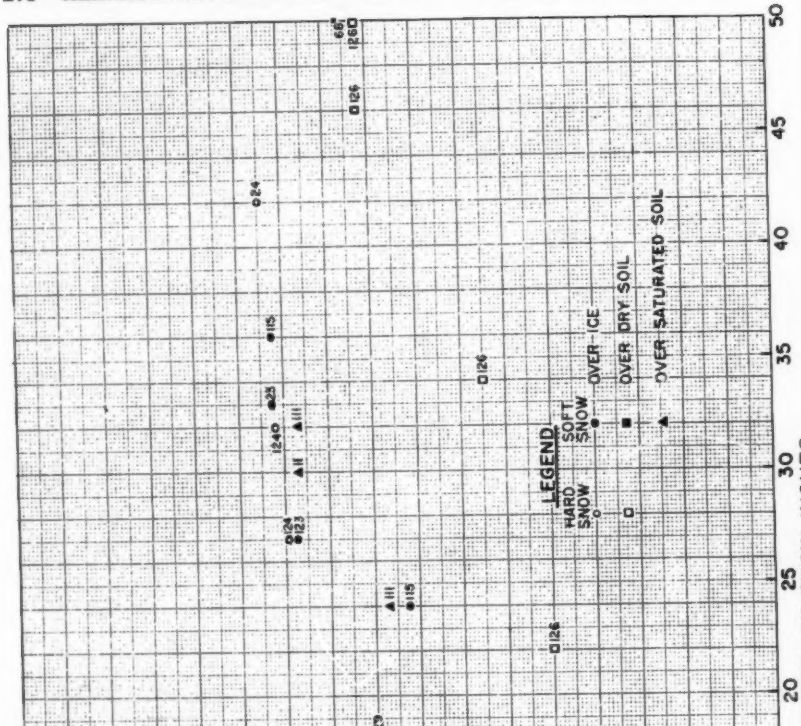

Fig. 10. Relation between depth, and insulation value (difference between snow temperature and ambient air temperature average for previous week) of hard and soft snow, for Feb. 26-27, 1954.

hard-packed snow, others, soft. Some stations have ice between the snow and the soil.

During the winter of 1953-4, temperatures of snow at different depths were taken. Where the thermal gradient of the snow, i.e. the difference in °C between the temperature of the snow at a given depth and that of the ambient air averaged over the previous week, is plotted against snow depth (Fig. 10), a relationship similar to that noted for snow depth and temperature of the soil at a 12-inch depth is found. In both cases, beyond approximately a 20- to 25-inch depth of snow, the insulating effect of the snow alters little. In the case of packed snow over dry ground, such as is found at station 126, the insulation afforded at greater depths is less than for other pack snow stations which are over ice (124, 24). At snow depths of 6 inches or less, the thermal gradient is shallower for the ambient air temperatures of the afternoon when the readings made are reflected more nearly by the snow temperature.

Hard snow, as is expected, is a better conductor of heat than is soft snow (Figs. 9 and 10). While this may be in part a result of the shallower snow cover, the flatter thermal gradient at stations 26 and 126 provides further evidence that hardness of snow is another important factor.

The thermal gradient of snow fluctuates through the winter such that it increases until December then gradually falls to almost zero by late April or May. An example of this is shown in Figure 11. This change in gradient would normally be expected to follow the change in ambient air temperature through the winter: with lowering of ambient air temperature the gradient would increase, with raising of ambient air temperature the gradient would decrease. However, the steepest gradient occurs in mid-December, while the ambient air reaches its lowest temperature early in January. This suggests that a factor other than the insulating value of snow is operative. This factor is probably the "warming" effect of the soil below.

Figure 13 illustrates the change in thermal gradient of 20 to 25 inches of snow at station 111 during the winter of 1953-4. This depth was selected because with this thickness and more of snow, less change appears to take place in the thermal gradient at a given time; i.e. the snow has reached its maximum insulating effect (Fig. 10). However, the gradient increased until a sudden rise in the ambient air temperature (rain was recorded for February 7) caused a drop in its slope. With the end of February, the gradient rose again with the concurrent decrease in air temperature, then fell off until, by May, it was almost flat. The drop in February and through April reflects the diminishing difference between snow and ambient air temperatures, as well as the increasing wetness and consequent increased conductivity of the snow.

The temperature of the snow at the surface fluctuates comparatively little throughout the winter (Fig. 12). Eight inches above the soil surface, however, the temperature fluctuates more erratically, indicating the decrease in the effect of the temperature of the soil below, and an increase in the effect of the temperature of the air above.

Summary

Soil temperatures were obtained at varying depths through the active layer at regular intervals at forty stations in swamp and high dry areas of forested and non-forested localities of the Churchill, Manitoba region, by means of copper-constantan thermocouples and a portable potentiometer. Some have been recorded since November, 1950, some since November, 1951, and the remainder since September, 1953; snow depth and water level measurements have been recorded since November, 1951; snow temperatures have been recorded since November, 1953.

The results of the studies may be summarized as follows:

1. At Churchill, the average thickness of the active layer ranges from 8 to 12 feet for sandy soil; from 3 to 8 feet for clay, clay-sand, or clay-gravel soils topped by a 6- to 12-inch layer of peat. In swamp areas the depth of the upper limit of perennially frozen ground varies depending upon the amount and depth of water. Under water, or in areas of saturated soil, the perennially frozen ground may be 43 to 92 inches below the surface; where tussocks, hummocks, mounds and hillocks occur, the level of the frost rises to within 34 to 73 inches of the surface of the ground.

2. Deeper levels of perennially frozen ground are found in areas with a thin peat overburden than in those areas with a thicker overlying layer of peat.

3. Where plant cover has been removed, the frost level may recede as much as 50 inches during a period of 3 years.

4. Soil temperatures over a period of a year follow a curve of increase and decrease which, on the average, lags behind that of ambient air temperature.

5. During the summer the maximum depth of thaw of the active layer is reached between August 15 and October 15; the average date is September 15.

6. During the winter months the lower limits of the active layer reach their lowest temperature between December 15 and May 15; the average date is approximately March 1.

7. The temperature inversion due to a temperature lag is observable with temperatures systematically lagging as the depth increases.

8. The first measurable snow appears in the fall about 10 to 28 days after the average ambient air temperature reaches 0° C, and disappears in the spring as early as 23 days before and as late as 24 days after the date at which the average ambient air temperature reaches 0° C. The snow disappears earliest where its accumulation has been slightest during the winter months.

9. Generally the lower soil depths freeze or thaw later than the upper by as much as a week to a hundred or more days.

10. In winter, the surface temperatures of soil in ponds in wooded areas with normal snow cover of over 15 inches vary from +0.5° to —4.0° C; in the non-wooded areas where hard snow prevails to depths rarely exceeding 10 inches, the temperature may reach —15° C. Where insulated by

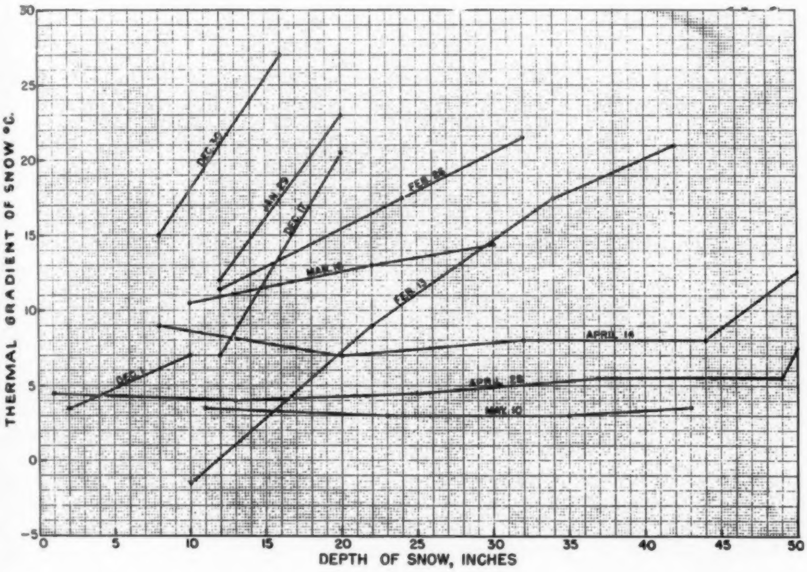

Fig. 11. Relation between insulation value of snow, and snow depth, station no. 111, winter of 1953-4.

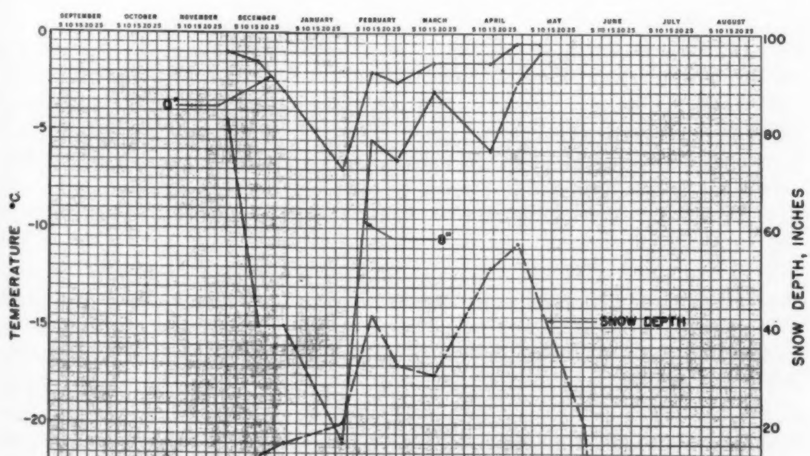

Fig. 12. Change in temperature of snow at 0 inches, and 8 inches above soil surface, with change in snow depth, at station no. 111, winter of 1953-4.

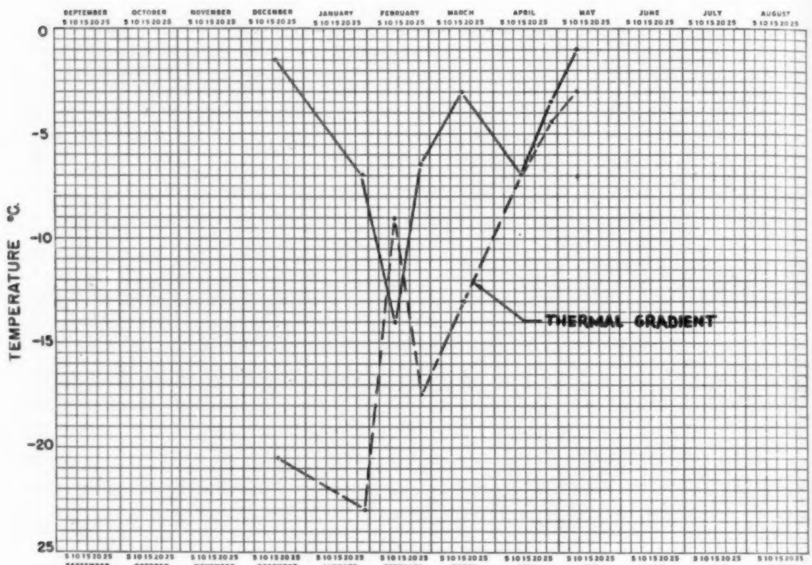

Fig. 13. Change in temperature, and thermal gradient of snow 20 inches below surface of snow, at station no. 111, through winter of 1953-4.

a thick, soft mantle of snow in the forest, the extremes of the drier soils are —7° to —9° C.

11. Where snow accumulation is great during the early part of the winter the lower levels of the active layer may never go as low as 0° C; rather, they may remain at temperatures just above this value. The same situation is found where the upper limit of perennially frozen ground occurs at great depths, as in wet sandy soils or where there is deep standing water.

12. The role of snow as it affects the rate of freeze and thaw of the active layer varies according to its hardness, moisture content and depth. During the winter months, the snow which collects in the densely wooded areas is soft and, as a rule, deep. In the thinly wooded areas and in the open it is hard packed. Hard and/or wet snow was found, as expected, to be a better conductor of heat than snow which was soft and/or dry. The thermal gradient of the snow, i.e. the difference in temperature of the snow with depth, is affected by changes in ambient air temperature and by the temperature of the soil, ice or water below. The thermal gradient was taken to indicate the insulating effect of the snow at the particular time involved.

Acknowledgements

Special thanks are due Mr. B. R. Irvine for making most of the readings at the stations and for his suggestions and criticisms as the program was

being carried out. Thanks are also due the Physics and Chemistry Section of the Laboratory for designing and building the necessary equipment; to Dr. J. F. Manery for assistance in instituting the programs, and to other members of the scientific staff of this Laboratory for their assistance and suggestions throughout the progress of this program.

References

American Institute of Physics. 1941. Temperature, its measurement and control in science and industry. New York: Reinhold Publishing Co.

Atkinson, H. B. and C. E. Bay. 1940. Some factors affecting frost penetration. Trans. Am. Geophy. Un. Pt. 3: 935-947.

Beckel, D. K. Brown, C. E. Law and B. R. Irvine. 1954. Major terrain types of North American tundra and boreal forest areas with examples from the Churchill, Manitoba area. Defence Research Board, Canada, Defence Research Northern Laboratory, Tech. Note No. 37.

Blakely, T. S. 1954. Reports of solar radiation. Defence Research Board, Canada, Defence Research Northern Laboratory, Tech. Note No. 35.

Boughner, C. C. and M. K. Thomas. 1948. Climatic summaries for selected meteorological stations in Canada, Newfoundland and Labrador. Toronto: Department of Transport, Meteorological Division, Vol. II.

Boyoucos, G. J. 1913. An investigation of soil temperatures and some of the factors influencing it. Michigan Agricultural College Experimental Station Tech. Bull. No. 17: 196 pp.

Canada, Department of Transport. 1947. Climatic summaries for selected meteorological stations in the Dominion of Canada. Toronto: Department of Transport, Meteorological Division, Vol. I.

Cook, Frank A. 1955. Near surface soil temperature measurements at Resolute Bay, Northwest Territories. Arctic 8: 237-249.

Crawford, C. B. 1952. Soil temperatures and thermal properties of soils (a review of published records) in "Frost action in soils, a symposium", Highway Research Board, Special Report No. 2. National Academy of Sciences, National Research Council, Canada, Pub. 213: 17-39.

Diebold, G. H. 1937. Some interrelationships between soil characteristics, water tables, soil temperatures and snow cover in the forest and adjacent open areas in south-central New York. Thesis, Ph.D., Cornell Univ.: 1-157. Append.

Forbes, J. D. 1837. Account of some experiments on the temperature of the earth at different depths, and in different soils, near Edinburgh. Trans. Roy. Soc. Edinburgh, Vol. 16.

Johnston, W. A. 1930. Frozen ground in the glaciated parts of northern Canada. Roy. Soc. Can., Proc. and Trans. 3rd ser. 24(4): 31-40.

Kemler, Emergy, N. & S. Oglesby, Jr. 1950. Heat pump applications. Toronto: McGraw-Hill Book Co., Inc., p. 137.

Lytle, E. A. L. 1954. A portable potentiometer for measuring the e.m.f.'s of thermocouples. Defence Research Board, Canada, Defence Research Northern Laboratory Tech. Note No. 30.

Weaver, J. E. & F. F. Clements. 1929. Plant Ecology. Toronto: McGraw-Hill.

Williams, M. Y. 1948. The geological history of Churchill, Manitoba. Western Miner 21(6): 39-42.

REVIEWS

PAGEANT OF THE NORTH.

A photographic adventure in Canada's north. Edited by CLIFFORD WILSON *The Ryerson Press, Toronto. 1957. 11¼ x 8¼ inches; 176 pages. $5.50.*

About ten years ago an attractive and popular book of photographs reproduced from *The Beaver* was published. It provided in convenient form a generous selection from the many hundreds of technically outstanding and beautiful illustrations for which the Hudson's Bay Company magazine is famous.

The present volume contains about 175 black and white full-page photographs also reproduced from *The Beaver,* about half of them having been taken since the earlier volume was published. Clifford Wilson has arranged the photographs into a dozen groups and has provided a brief introduction for them. Representative titles of these "chapters" are "Indians", "Birds and Beasts", "Ships and Boats", "Eskimos", "The Newcomers".

The work of more than fifty photographers is represented — which itself emphasizes how much *The Beaver* has done and continues to do to encourage high quality photography in the frontier regions of Canada. While many of the pages show the work of professionals whose reputations were already established elsewhere — Margaret Bourke-White of *Life* is notable among them — there are also many amateur photographs which are in no way inferior, among them the work of well-known northern travellers such as L. A. Learmonth, J. H. Webster and A. W. Banfield.

Photographs which have stood the test of the years and which seem likely to hold a permanent place as northern documentaries include Brigdens' "Plains Indian in native dress", F. Dalman's "Manitoba Trapper", Bob Stewart's pictures of Eskimos made a generation ago, R. N. Hourde's "portraits" of the venerable "Distributor" and the extraordinarily moving studies of water birds by the late Lorene Squire, to whom the book is fittingly dedicated.

The reviewer was glad to see A. L. Learmonth's "Northwest Passage, Bellot Strait" once more, if only as a timely reminder that this route between west and east was familiar to traders long before its much publicized transit by naval vessels in the 1957 summer.

Pageant of the North is a useful book to keep on hand for occasional study and reference (even though the reviewer failed to locate among its many wildlife views a representative shot of "an arctic seal" called for urgently by an enquiring sculptress). The book is also very suitable to send as a gift to friends at home or overseas, particularly those who merit something characteristically Canadian.

Long may the happy teamwork of the Hudson's Bay Company, Clifford Wilson, Brigdens Ltd. (who made the engravings), the printers and publishers continue to give us such splendid, balanced and wide ranging views of the northland.

TREVOR LLOYD

DAWN IN ARCTIC ALASKA.

By DIAMOND JENNESS. *Minneapolis: University of Minnesota Press, 1957. 5⅝ x 8¾ inches; 222 pages; numerous illustrations by* GIACOMO RAIMONDI; *6 sketch maps. $5.50 in Canada.*

The "dawn" of this title refers to a period of new contact with people and

things of the world outside the Arctic and the beginning of acculturation among Eskimos of the Beaufort Sea coast. The book presents a year, the first one, in Dr. Jenness's work among Eskimos. The year was 1913-14; the occasion, the Stefansson Arctic (or Stefansson-Anderson) Expedition.

Because of separation from their ship, several members of the expedition, including the author, had a lean and difficult winter. But probably Dr. Jenness learned more and gives us more of the daily life of his Eskimo hosts as a result of his great dependence on them. Dreary, small, and monotonous as it is, still the winter story of hunger and confinement is the real contribution of the book, since it gives the "feel" of the trappers' life without glamour or drama. This is realism without even a capital "R".

The summer story (1914) has another value: an account of the author's archaeological work, especially on Barter Island. This has biographical interest for his numerous friends, for young archaeologists learning the history of their field, and for inhabitants of the area. Those today manning the northern bases and radar sites probably find it hard to imagine the life of the area or the appearance of old sites before they came along.

The book contains little ethnography in detailed descriptions of techniques and beliefs. It does have, however, a good picture of the patterns of mobility forty years ago, both coastwise and between inland and coast. If one wanted a base from which to start an acculturation account of the area, this book would provide several good building blocks.

Life did not change so completely or so fast, though, as the author suggests. His assumption and misinformation regarding changes, evidently given him by others after he ceased work in Alaska, have led to the principal errors of the book. The reviewer had the interesting experience of visiting the book's area while reading it. On the basis of visits to Wainwright, Barrow and Barter Island, September 1957, we can reassure everyone that the people of Point Hope, Wainwright, and Barrow have continued whaling right to 1957, contrary to the statement (page 127) that "whaling remains a mere memory." On information from Fr. Thomas Cunningham, S.J., who has lived in recent years on Diomede Island and has been on the Soviet side of Bering Strait since 1926, it can be said also that visiting and trade between Siberia and Alaska did not cease in that year, as stated (page 157). Trade between Eskimos on the two sides of the Strait continued until 1948.

These are of course only two errors in a book that otherwise seems accurate. Certainly its calm style is reassuring. It consistently eschews the dramatics and self-praise of so many northern journals. Although this is not a very exciting story, we are glad that Dr. Jenness after so many years has told it and especially glad that the winter described here did not discourage him from continuing in what turned out to be an important career in arctic archaeology.

MARGARET LANTIS

BIRTHPLACE OF THE WINDS.

By TED BANK II. *New York: Thomas Y. Crowell 1957. 274 pages; illus., plates, maps, diagrams. $4.50.*

As the dust cover informs us, this book is "an informal account of scientific exploration among the islands of the Bering Sea". As the book itself presents it, Mr. Bank's "scientific exploration" is a continuous series of excitement and disappointment, thrill, romance, mystery, and heroism, recounted in the old stereotyped patterns of the travelogue to remote places produced *pour épater le bourgeois*. The "scientific" in Mr. Bank's "exploration" appears to consist in rummaging ghostly burial places cursed by the ancient beliefs of the Aleuts, scaling dangerous volcanos, and plucking an assortment of odd plants along with oddments of esoteric information of all descriptions. These activities are illustrated with sketches of mummies, photos of skulls, plants, rugged scenery, and people, drawings of queer, unexplainable bone, stone, and wooden objects. Human interest is added by the succession of hairbreadth escapes and daring adventures with nature, by the perennial assistant exploding 'Godamighty' at every new

discovery, and by the poor, downtrodden, clever, dirty Aleuts mumbling in the same broken English that is attributed by explorers of remote islands alike to Polynesians, Melanesians, Japanese, and native nesians of all races. The photographs are good, though hardly worth the price of the book.

The work seems to have been produced primarily to sell to the numerous personnel who are or have been stationed in the Aleutian Islands during and since the last war. And except to these people the exotic surroundings of the Aleutians do not succeed in giving to the author's doings and gossipings a real scientific import or purport. In the end one is still left wondering where the winds are born.

GORDON H. MARSH

INSTITUTE NEWS

The Polar Record

The Scott Polar Research Institute in Cambridge, England has made the following announcement.

The Polar Record is being obliged to fall in line with almost all other journals in Britain and increase the cost to subscribers as the present price was fixed in 1952 and production costs have risen some 25 per cent since that date. Beginning with the January 1958 issue, Vol. 9, No. 58 the price will be 10s. 6d. an issue or £1 11s. 6d. a year. North American subscribers, who may join through the Montreal office of the Arctic Institute of North America at 3485 University Street, Montreal, will be charged $1.75 an issue or $5.00 per year. These rates include postage. For the convenience of Arctic Institute members the Montreal office is prepared to handle subscriptions to *The Polar Record* together with the normal dues for *Arctic* so that one letter and one payment will cover both.

Visitors to Montreal

During the afternoon of September 17, "Bishop Mountain House" received an informal visit from a group on its way from the International Union of Geodesy and Geophysics' meetings held in Toronto to the Soviet Union. The visitors were Dr. Kort, Director of the Oceanological Institute, Moscow, and Dr. Tolstikov, Deputy Chairman of the Northern Sea Route Administration, Moscow. They were conducted through the Institute by Dr. M. J. Dunbar and Dr. S. Orvig and were received by the Executive Director, Mr. A. T. Belcher.

Gifts to the Library

The Institute Library gratefully acknowledges gifts of books and reprints from the following persons and organizations:

H. Butler
D. V. Ellis
J. Fried
J. Haller
Y. I. Tolstikov
Jane S. Tucker
D. E. Wohlschlag
Argentina, Instituto Antartico Argentino
Canada, Defence Research Board
International Civil Aviation Organization, Library
McGill University, Redpath Museum
Wisconsin University, Department of Sociology and Anthropology

Richard Carleton Hubley — 1926-1957

On October 29, 1957, word was received by the Institute of the death of Richard Hubley while leading the International Geophysical Year glaciological program on McCall Glacier, Brooks Range, Alaska.

Dr. Hubley's death has come at a time when he has assumed national — and even international — leadership in his chosen field. North American science has been slow in building a coterie of scientists in the field of glaciology. Of those we have, Richard Hubley was one of the most distinguished. Science can as ill afford his loss as can we who knew him as a companion in the office and among the high snows.

NORTHERN NEWS

New polar ship

On October 9 the Aalborg Shipyard, Ltd, delivered to the J. Lauritzen Company of Copenhagen the new polar expedition ship M.S. *Thala Dan*. This company has for long specialized in northern marine transport and, in addition to its fleet of bulk cargo vessels, now, with the acquisition of the M.S. *Thala Dan* owns three ships equipped to transport the material and personnel of polar expeditions. The M.S. *Thala Dan* is of a design similar to, but is larger than either of its predecessors the M.S. *Kista Dan* and the M.S. *Magga Dan*. Of these two ships a drawing and a description respectively were published in *Arctic* Vol. 8, No. 1, 1955.

The *Thala Dan* like its predecessors, is designed to serve as a passenger-cargo ship in which the amount of space given to passengers or cargo can be altered as needed. As a cargo vessel the *Kista Dan* is of 1100 tons deadweight, and the *Magga Dan*, as a passenger vessel, was designed to have a deadweight of about 1650 tons. The new *Thala Dan* as a cargo vessel has a deadweight of 2150 tons with a draught of 6.27 metres. With this disposition the ship can carry 12 passengers. However, the passenger accommodation can be adapted to take 36 persons, in which case the ship is loaded to a draught of 6.00 metres, with a corresponding deadweight of about 1950 tons.

M. S. *Thala Dan*

To meet the needs of navigation in ice special features have been incorporated in the design of the *Thala Dan*. These features are similar to those of the two earlier-built ships, but have been further refined as a result of the experience obtained in the working of those two vessels. The hull is specially strengthened, to specifications greater than those required for the Finnish ice class A I, whilst the whole ship is built to accord with the highest class listed by Lloyds. The *Thala Dan* is fitted with an ice-breaker stem, an ice cutter and with fins to protect the propeller from ice. More powerful than her predecessors, the ship has a 7-cylinder turbo-charge Diesel unit as her main engine. It is a single-acting, direct reversible two-stroke engine, developing 2200 initial horsepower at 300 revolutions per minute.

Of particular interest are the navigational aids included in the design. The quarter-deck has space for a helicopter or small aeroplane to be used for reconnoitring ice conditions, whilst the ship can be steered and directed from a crow's nest built into the foremast. Access to the crow's nest, which is about 20 metres above sea level, is by the inside of the mast. The equipment in the crow's nest duplicates and can be operated independently of the manœuvring gear in the wheel-house.

The living quarters for the crew, on the 'tweendeck aft, and for the officers, in the deck-house aft, are handsomely furnished. Although not mentioned in the published list of specifications it is presumed that the *Thala Dan* has the same type of insulated holds as those which were built into the *Magga Dan*. It is presumed too that performance figures, also not yet released, are similar or superior to those of the *Magga Dan*, which was listed as having a speed of 12 knots and a range of 16000 miles. There can be little doubt that the M.S. *Thala Dan* is very well equipped to perform its function of expedition transport in polar areas.

Archaeological investigations in the Arctic and subarctic, 1957.

At the request of the editor, I shall attempt to summarize the various archaeological activities that occurred in the Arctic and subarctic during the last summer. This summary will be kept relatively brief.

Members of a party called Operation Hazen organized by the Defence Research Board as part of the Canadian program for the International Geophysical Year worked on archaeological remains on Ellesmere Island, discovering four sites of aboriginal structures. One, about twenty miles north of Lake Hazen; one on the shores of Lake Hazen; and two along the Ruggles River. Few artifacts were uncovered since they did no digging. These sites, however, are of considerable significance for not only are they the northernmost sites in the Canadian Arctic but they are situated along the hypothetical route of migration from the Canadian Arctic to Greenland. Investigation of these sites has been planned for the 1958 field season by the National Museum of Canada.

Moving a little further south, Dr. Jorgen Meldgaard of the National Museum of Denmark, returned to the Alarnerk Site in the Igloolik area on the Melville Peninsula after two season's absence. The previous season's efforts had been concentrated on Dorset structures and remains belonging to five periods. These Dorset remains were on ancient beaches from 8 to 22 metres above sea level. This season's endeavours concentrated on older remains (dated roughly 3400 years ago by Carbon 14) on beaches from 26 to 54 metres above sea level. I shall mention only a few of the more salient facts of his finds. Most of these early pre-Dorset remains appear to belong to an early and late period having burins, micro-blades, side-blades, small end-blades, and other artifacts indicating a close relationship with both the Cape Denbigh Flint Complex of Alaska as well as with Sarqaq of Greenland. The sequential changes in his artifact types from these pre-Dorset remains closely parallel changes of types from the four middle cultural phases from the Firth River in the Canadian

Yukon. Two particularly interesting features are that the latest of these remains on levels only a few metres above the earliest Dorset remains, do not appear to be a transition into Dorset. The other significant feature of these early remains is that they have distinctive toggle-headed harpoons that indicate a much earlier time period for this implement and inferred hunting technique than had previously been suspected.

Mr. William E. Taylor of the National Museum of Canada undertook preliminary excavation and survey in the interior as well as the coast and adjacent islands of the northern part of the Ungava Peninsula. His activities in the interior were at Payne Lake where he found about forty house remains, of which he excavated four. All of these were Dorset with one having a slight overlay of Eskimo remains. On the coast at the estuary of the Payne River, he uncovered another Dorset site as well as one Dorset burial. He has stated that at least superficially the skull is like those of modern Eskimos in the area. At Sugluk, seven sites were investigated and five of these appear to be Dorset villages with semi-subterranean rectangular houses.

My endeavours were in the southern part of the Yukon Territory between Johnsons Crossing, Kluane Lake, Dawson City, and Mayo. Ninety-seven sites were discovered as well as about 1,000 artifacts. The sites seem to belong to at least six different artifact complexes, four of which were below the volcanic ash layers dated about 300 A.D. Twenty-eight of the sites are micro-blade sites.

In Alaska, Dr. Ivar Skarland of the Department of Anthropology of the University of Alaska, during the last part of the summer, investigated interior sites on which "Yuma" projectile points have been found.

Mr. Gordon Lowther, of the McCord Museum of McGill University of Montreal, undertook archaeological survey in the Old Crow Flats in the Yukon Territory. He was most successful in finding fourteen archaeological sites as well as places at which mammoth bones occurred. As yet, his materials have not been analysed but they are from an area that it is most difficult to find sites in, and one which is probably very important for the understanding of the relationships between the coastal or tundra cultures and those from the boreal forest or interior.

R. S. MacNeish
National Museum of Canada

REPRINTS FROM ARCTIC AVAILABLE AT THE MONTREAL OFFICE

(The figure in **bold type**, indicating the volume, is followed by the number of the issue, the number of pages, and the price, including postage).

ARMSTRONG, T. Sea ice studies. **7**,3-4 (5pp.) 15c.
AUBERT DE LA RUE, E. Geological survey through the Ungava Peninsula. **1**,2 (1p.) 10c.
BAIRD, P. D. Glaciological research in the Canadian Arctic. **8**,2 (13pp.) 25c.
BAIRD, P. D. and R. P. SHARP. Glaciology. **7**,3-4 (12pp.) 25c.
——————Baffin Island expedition, 1953: a preliminary field report. **6**,4 (26pp.) 25c.
BANFIELD, A. W. F. Notes on the mammals of the Mackenzie District, N.W.T. **4**,2 (10pp.) 25c.
BEALS, C. S. *et al.* Problems of geophysics in the Canadian Arctic. **7**,3-4 (11pp.) 30c.
BENNINGHOFF, W. S. Interaction of vegetation and soil frost phenomena. **5**,1 (11pp.) 25c.
BERREMAN, G. D. Effects of a technological change in an Aleutian village. **7**,2 (6pp.) 20c.
BERTRAM, G. C. L. Pribilof fur seals. **3**,2 (12pp.) 25c.
—————— The Scott Polar Research Institute. **5**,3 (4pp.) 10c.
BLACK, R. F. Eolian deposits of Alaska. **4**,2 (23pp.) 50c.
BOCHER, T. W. Botanical investigations in southwest Greenland, 1946. **4**,1 (4pp.) 10c.
BOCHER, T. W. *et al.* Recent biological research in Greenland. **7**,3-4 (12pp.) 10c.
BOGVAD, R. Nepheline syenite and iron ore deposits in Greenland. **3**,2 (9pp.) 25c.
BRANDLY, P. J. and R. RAUSCH. A preliminary note on trichinosis investigations in Alaska. **3**,2 (3pp.) 10c.
BROWN, G. M. Cold acclimatization in Eskimo. **7**,3-4 (11pp.) 25c.
BUGGE, A. The native Greenlander — a blending of old and new. **5**,1 (9pp.) 25c.
BUSHNELL, V. C. Marvin's ice shelf journey, 1906. **9**,3 (12pp.) 35c.
BUSS, I. O. The upland plover in southwestern Yukon Territory. **4**,3 (10pp.) 25c.
CHRISTENSEN, N. O. Elections in Greenland. **5**,1 (2pp.) 10c.
CLARKE, C. H. D. Wildlife research in the North American Arctic. **7**,3-4 (11pp.) 25c.
COLBERT, L. O. Geophysical research in Alaska. **7**,3-4 (6pp.) 15c.
——————Tidal data in the North American Arctic. **7**,3-4 (2pp.) 10c.
COLLINS, H. B. Archaeological research in the North American Arctic. **7**,3-4 (11pp.) 20c.
COOK, F. A. Near surface soil temperature measurements at Resolute Bay, Northwest Territories. **8**,4 (13pp.) 30c.
CRARY, A. P. *et al.* Preliminary report on scientific work on "Fletcher's Ice Island", T3. **5**,4 (13pp.) 20c.
DAVIES, F. T. The ionosphere over northern Canada. **7**,3-4 (3pp.) 15c.
DUNBAR, M. J. Arctic and subarctic marine ecology: immediate problems. **6**,2 (16pp.) 25c.
——————*Calanus*, new arctic research vessel. **2**,1 (2pp.) 10c.
——————Langthen og nordpaa (book review). **2**,1 (4pp.) 10c.
——————A note on climatic change in the sea. **7**,1 (4pp.) 10c.
ELLIS, D. V. Some observations on the shore fauna of Baffin Island. **8**,4 (13pp.) 30c.
FRANKL, E. J. Crossing north Peary Land. **8**,3 (8pp.) 25c.
FRASER, J. K. Identification of Petitot's Rivière le Roncière-le-Noury. **5**,4 (11pp.) 20c.
FREEMAN, T. N. Some problems of insect biology in the Canadian Arctic. **5**,3 (3pp.) 10c.
FREEMAN, T. N. and C. R. TWINN. Present trends and future need of entomological research in northern Canada. **7**,3-4 (9pp.) 15c.
GRAHAM, M. English fishery research in northern waters. **6**,4 (8pp.) 20c.
HAAS, E. DE. A method for measuring the movement of rocks and glaciers with simple equipment. **6**,4 (3pp.) 15c.
HACHEY, H. B. Canadian interest in arctic oceanography. **2**,1 (8pp.) 25c.
HAMMER, M. Some aspects of the distribution of microfauna in the Arctic. **8**,2 (12pp.) 25c.
HARE, F. K. Two pictures of the recent past. **6**,1 (3pp.) 10c.
—————— The upper air over northern Canada (book reviews). **3**,1 (2pp.) 10c.
HATTERSLEY-SMITH, G. *et al.* Northern Ellesmere Island, 1953 and 1954. **8**,1 (35pp.) 30c.
HELK, J. V. and M. DUNBAR. Ice islands — evidence from north Greenland. **6**,4 (9pp.) 20c.
HOLTSMARK, B. E. Insulating effect of a snow cover on the growth of young sea ice. **8**,1 (6pp.) 15c.
IRVING, L. The naming of birds by Nunamiut Eskimo. **6**,1 (9pp.) 10c.
ISELIN, C. O'D. Oceanographic problems of the Arctic Ocean. **7**,3-4 (4pp.) 10c.
JOESTING, H. R. Geophysical exploration in Alaska. **7**,3-4 (11pp.) 25c.
KATZ, H. R. Journey across the nunataks of central east Greenland, 1951. **6**,1 (13pp.) 25c.
KIRKPATRICK, C. M. *et al.* Notes on captive sea otters. **8**,1 (14pp.) 20c.
KNUTH, E. An outline of the archaeology of Peary Land. **5**,1 (17pp.) 25c.
KOENIG, L. S. *et al.* Arctic ice islands. **5**,2 (38pp.) 50c.
LAFOND, E. C. Physical oceanography and submarine geology of the seas to the west and north of Alaska. **7**,2 (9pp.) 20c.
LANTIS, M. Problems of human ecology in the North American Arctic. **7**,3-4 (14pp.) 25c.
LAUGHLIN, W. S. and G. H. MARSH. A new view of the history of the Aleutians. **4**,2 (15pp.) 25c.

LEAHEY, A. Soil and agricultural problems in subarctic and arctic Canada. 7,3-4 (6pp.) 15c.
LEGGET, R. F. Permafrost research. 7,3-4 (6pp.) 10c.
LITTLEWOOD, C. A. Gravity measurements on the Barnes Ice Cap, Baffin Island. 5,2 (7pp.) 25c.
LLOYD, T. Discovery of Russian hydrographic bottles and barges off west Greenland. 5,2 (1p.) 10c.
————Meddelelser om Den gronlandske Kirkesag. 5,3 (2pp.) 10c.
————North: the nature and drama of the polar world, by Kaare Rohdahl (book review). 6,4 (2pp.) 10c.
MACCARTHY, G. R. Recent changes in the shoreline near Point Barrow, Alaska. 6,1 (8pp.) 20c.
MADILL, R. G. The search for the north magnetic pole. 1,1 (11pp.) 25c.
MALAURIE, J. The French geographical expedition to Thule, 1950-1951: a preliminary report. 8,4 (13pp.) 30c.
MANNING, T. H. Narrative of an unsuccessful attempt to circumnavigate Banks Island by canoe in 1952. 6,3 (28pp.) 40c.
————Narrative of a second Defence Research Board expedition to Banks Island, with notes on the country and its history. 9,1-2 (77pp.) 60c.
————Notes on the fish of Banks Island. 6,4 (2pp.) 10c.
————Remarks on the reproduction, sex ratio, and life expectancy of the varying lemming, *Dicrostonyx groenlandicus*, in nature and captivity. 7,1 (13pp.) 25c.
————Remarks on the tides and driftwood strandlines along the east coast of James Bay. 4,2 (9pp.) 25c.
MANSFIELD, A. W. Eastern arctic fisheries investigations, 1947-55. 8,2 (3pp.) 35c.
MARIER, G. Recent studies on vitamins (book review). 4,1 (3pp.) 10c.
MARSHALL, E. W. Structural and stratigraphic studies of the northern Ellesmere ice shelf. 8,2 (6pp.) 20c.
MEIER, M. F. *et al.* Preliminary data from Saskatchewan Glacier, Alberta, Canada. 7,1 (24pp.) 35c.
METCALF, W. G. A note on arctic oceanography and the Lomonosov Range. 7,2 (2pp.) 10c.
MICK, A. H. and H. A. JOHNSON. Soil resources and agricultural development in Alaska. 7,3-4 (13pp.) 25c.
MILLER, R. S. A survey of the mammals of Bylot Island, N.W.T. 8,3 (11pp) 25c.
MONTGOMERY, M. R. Further notes on ice islands in the Canadian Arctic. 5,3 (5pp.) 10c.
MORRISON, P. R. and W. J. TEITZ. Observations on food consumption and preference in four Alaskan mammals. 6,1 (6pp.) 10c.
MUNTZ, A. P. Recent glacier activity in the Taku Inlet area, southeastern Alaska. 8,2 (13pp.) 25c.
NIELSEN, F. Planned reforms in Greenland. 4,1 (6pp.) 10c.
NUTT, D. C. The *Blue Dolphin* Labrador expeditions, 1949 and 1950. 4,1 (10pp.) 25c.
————Second (1948) U.S. Navy antarctic development project. 1,2 (5pp.) 10c.
PAULS, F. P. Enteric diseases in Alaska. 6,3 (8pp.) 20c.
PETERSEN, H. The Danish meteorological service in Greenland. 1,1 (7pp.) 25c.
POLUNIN, N. *et al.* Aerobiological investigations in the Arctic and Subarctic. 1,1 (2pp.) 10c.
PORSILD, A. E. A biological exploration of Banks and Victoria islands. 3,1 (10pp.) 25c.
RAE, R. W. Joint arctic weather project. 4,1 (9pp.) 25c.
————Meteorological activities in the Canadian Arctic. 7,3-4 (10pp.) 25c.
RAND, A. L. The ice age and mammal speciation. 7,1 (5pp.) 15c.
RAUSCH, R. Notes on the Nunamiut Eskimo and mammals of the Anaktuvuk Pass region, Brooks Range, Alaska. 4,3 (50pp.) 50c.
————Observations on a cyclic decline of lemmings (*Lemmus*) on the arctic coast of Alaska during the spring of 1949. 3,3 (12pp.) 25c.
————On the status of some arctic mammals. 6,3 (58pp.) 50c.
RAWSON, D. S. Limnology in the North American Arctic and Subarctic. 6,3 (7pp.) 15c.
REED, J. C. and H. S. BOSTOCK. Research in geology and geomorphology in the North American Arctic and Subarctic. 7,3-4 (12pp.) 20c.
REICHELDERFER, F. W. Meteorological services in Alaska. 1,1 (8pp.) 25c.
[Field] research projects sponsored by the Arctic Institute of North America. 7,3-4 (13pp.) 15c.
REX, R. W. Microrelief produced by sea ice grounding in the Chukchi Sea near Barrow, Alaska. 8,3 (10pp.) 20c.
ROBINSON, E. Some instances of unstable surface temperature conditions during an arctic winter. 8,3 (10pp.) 20c.
RODAHL, K. "Spekk-finger" or sealer's finger. 5,4 (6pp.) 10c.
ROSS, J. E. R. Geodetic investigations in the Canadian Arctic. 7,3-4 (4pp.) 10c.
ROWLEY, G. W. Settlement and transportation in the Canadian North. 7,3-4 (7pp.) 20c.
SAILER, R. I. Invertebrate research in Alaska. 7,3-4 (9pp.) 25c.
SHARP, R. P. Glacial-meteorological investigations in Swedish Lapland (review article). 3,2 (4pp.) 10c.

c.

)

,2

k

.)

ry

by

d,

ng
7,1

of

elf.

7,1

0c.
xa.

ur

8,2

10c.

on,

t of

orth

op.)

ow,

ctic

cle).